THE ROLE OF SOIL ANALYSIS IN RESOURCE MANAGEMENT

PROCEEDINGS OF THE 9TH

B.C. SOIL SCIENCE WORKSHOP

FEBRUARY 21 AND 22, 1985

BC Ministry of Environment

ISSN 0821-0942

86-05739/

BC
E5
C
no.G38.16
1985
c.3

Ministry of Environment

MOE Technical Report 16

THE ROLE OF SOIL ANALYSIS IN RESOURCE MANAGEMENT

Proceedings of the Ninth British Columbia Soil Science Workshop

Held at the University of British Columbia, Vancouver, B.C.,
February 21st. and 22nd. 1985,
under the auspices of the B.C. Land Resource Science Lead Committee

Organizing Committee

H. A. Luttmerding
L. E. Lowe
T. M. Ballard

PROCEEDINGS PUBLISHED BY
SURVEYS AND RESOURCE MAPPING BRANCH

Victoria, B.C.
July 1985

Canadian Cataloguing in Publication Data

British Columbia Soil Science Workshop (9th : 1985 : University of British Columbia)
The role of soil analysis in resource management

(MOE technical report, ISSN 0821-0942 ; 16)

Includes bibliographical references.
ISBN 0-7726-0332-4

1. Soils - Analysis - Congresses. 2. Natural resources - Management - Congresses. I. B.C. Land Resource Science Lead Committee. II. British Columbia. Surveys and Resource Mapping Branch. III. Title. IV. Series.

S593.B75 1985 631.41 C85-092168-6

© Copyright 1985. B.C. Ministry of Environment
First Printing 1985.

FOREWORD

The Ninth British Columbia Soil Science Workshop was held February 21 and 22, 1985 at the University of British Columbia. Its' theme, "The Role of Soil Analysis in Resource Management", resulted from concerns expressed by the Soil Survey Subcommittee to the B. C. Land Resource Science Lead Committee that soil analyses were either not considered in some resource management decisions, or were applied inappropriately. Questions such as what kind of problems can soil analyses help solve, what analyses, and how many, are appropriate, and how should results be interpretated, were raised.

In an attempt to provide guidance to these and related issues, the Workshop was organized into four sessions. Each session addressed an aspect of soil analyses. The first highlighted the needs and expectations of soil analysis users, focusing mainly on agriculture, forestry and environment. The second addressed some approaches in soil analysis and interpretation while the third suggested methods for dealing with soil variability as well as providing some insights into what the future may hold. The fourth session consisted of a tour of the British Columbia Ministry of Environment's large, well-equipped laboratory at the University of British Columbia.

These Proceedings contain the papers and reports presented at the first three sessions as well as the workshop program and a list of the registrants. The Proceedings are, therefore, an up-to-date review of the role of soil analysis in resource management.

The Workshop interested a large number of people with about 125 individuals registered. Judging from their numerous supportive comments, the Workshop was a success.

All registrants receive a copy of the Proceedings. Further copies are available from MAPS-B.C., British Columbia Ministry of Environment, Parliament Buildings, Victoria, British Columbia or Publications Branch, British Columbia Ministry of Agriculture and Food, Parliament Buildings, Victoria, British Columbia.

H. A. Luttmerding,
Chairman,
Workshop Organizing Committee.

ACKNOWLEDGMENTS

The Workshop Organizing Committee would like to acknowledge the University of British Columbia for providing the facilities for the Workshop. Also acknowledged is the Department of Soil Science for supplying slide projectors, overhead projectors and other equipment as required.

Specially acknowledged are G. G. Runka, W. van Lierop, H. Schreier and L. E. Lowe for organizing and chairing the Workshop sessions. Without their effort, interest and enthusiasm the Workshop would not have been possible.

Also acknowledged are M. Browning, B. von Spindler and P. Synadinos for undertaking registration, operating the audio-visual equipment and generally assisting in making the Workshop a success. Also gratefully acknowledged are the staff of the Environmental Laboratory, British Columbia Ministry of Environment for providing a detailed and informative tour of their facilities.

The guidance and support provided by the B. C. Land Resource Science Lead Committee, especially L. Lavkulich and R. Bertrand, is sincerely acknowledged.

A special thank-you is extended to all the individuals who presented papers and reports at the Workshop. The interest and effort is deeply appreciated.

Also acknowledged is the British Columbia Ministry of Environment for publishing the Workshop Proceedings.

TABLE OF CONTENTS

	Page
FOREWORD	iii
ACKNOWLEDGEMENTS	v
TABLE OF CONTENTS	vii
SESSION ONE - THE NEEDS AND EXPECTATIONS OF SOIL ANALYSIS USERS	1
Opening Remarks and Welcome. L. M. Lavkulich, Chairman, B. C. Land Resource Science Lead Committee	3
Laboratory Analysis Applied On and Beyond the Farm. W. A. Herman, Pacific Soil Analysis Inc., Vancouver, B. C.	5
Horticultural Requirements and Interpretations. B. E. Mauza, B. C. Ministry of Agriculture and Food, Abbotsford, B. C.	8
Soil Chemical Data Requirements for Forestry Interpretations. T. Lewis, Consultant, Burnaby, B. C.	10
Chemical Attributes of Soils in Making Environmental Interpretations. J. H. Wiens, B. C. Ministry of Environment, Victoria, B. C.	13
Chemical Data in Soil Taxonomy. L. M. Lavkulich, University of British Columbia, Vancouver, B. C.	28
SESSION TWO - APPROACHES IN SOIL ANALYSES AND INTERPRETATIONS	33
Some Possible Approaches to Soil Nitrogen Availability Testing in Field Soils and Soil-less Mixes. M. Rowell, Norwest Soil Research Inc., Langley, B. C.	35
Bray's Soil Test Calibration Theory. R. A. Bertrand, B. C. Ministry of Agriculture and Food, Surrey, B. C.	46
Laboratory Determination and Interpretation of Soil Physical Properties. M. J. Goldstein, Soilcon Laboratories Ltd., Vancouver, B. C.	50
Soil Variability with Respect to Soil Test Values. A. L. van Ryswyk, Agriculture Canada, Kamloops, B. C., J. W. Hall, Agriculture Canada, Vancouver, B. C., and W. van Lierop, B. C. Ministry of Agriculture and Food, Kelowna, B. C.	63

TABLE OF CONTENTS (CONTINUED)

Page

A Comparison of Available Zinc Extractants For Southern Interior Orchard Soils. D. Nielsen and A. F. Mackenzie, McGill University, Ste. Anne de Bellevue, Que. and P. B. Hoyt, Agriculture Canada, Summerland, B. C. 64

Comparison of the Pipette and Hydrometer Methods for Determining Soil Particle-Size Distribution. H. Chuah, and W. van Lierop, B. C. Ministry of Agriculture and Food, Kelowna, B. C. 66

Factors Affecting Leaf Zn Concentration of 'McIntosh' Seedlings Grown in Nutrient Solution. G. H. Nielsen and E. J. Hogue, Agriculture Canada, Summerland, B. C. 73

15N Tracer Methodology in Soil Research. P. C. K. Pang, Canadian Forestry Service, Victoria, B. C. 81

Advantages of 15N Techniques in Interpreting Data For Soil Research. C. G. Kowalenko, Agriculture Canada, Agassiz, B. C. 83

Comparison of Laboratory Methods For Evaluating Plant-Available Soil Phosphorus. W. van Lierop, B. C. Ministry of Agriculture and Food, Kelowna, B. C. 90

SESSION THREE - HOW TO DEAL WITH SOIL VARIABILITY 97

Soil Variability: Does It Invalidate Our Interpretations? D. E. Moon, Agriculture Canada, Vancouver, B. C., and H. Schreier, University of British Columbia, Vancouver, B. C. 99

Geotechnical Site Investigations. J. Gadsby, Gadsby Geotechnical Consultants Ltd., Vancouver, B. C. 110

Present and Future Trends in Soil Fertility Management. J. D. Beaton, Potash and Phosphate Institute, Cochrane, Alta. 111

Implications of Soil Variability on Fertilizer Assessments For Crop Production. C. G. Kowalenko, Agriculture Canada, Agassiz, B. C. 129

Strategic Fertilizer Progammes For Individual Farmers in New Zealand. S. M. Smith, New Zealand Soil Bureau, Dunedin, New Zealand 133

TABLE OF CONTENTS (CONTINUED)

Page

Foliar Analysis For Deficiency Diagnosis and Fertilizer Prescription in Forestry: Variability Considerations. T. M. Ballard, University of British Columbia, Vancouver, B. C. 142

Quantitative Definitions of Stability Classes as Related To Post-Logging Clearcut Landslide Occurrence. M. Sondheim, B. C. Ministry of Environment, Victoria, B. C., and T. Rollerson, MacMillan Bloedel Ltd., Nanaimo, B. C. 154

Present and Future Trends in Quantitative Image Analysis and Its' Implications to Soil Science. R. J. Woodham, University of British Columbia, Vancouver, B. C. 177

SESSION FOUR - TOUR OF ENVIRONMENTAL LABORATORY 183
Summary 185

APPENDICES 187
APPENDIX 1 WORKSHOP PROGRAMME 189
APPENDIX 2 REGISTRANTS - 9th B. C. SOIL SCIENCE WORKSHOP 194

NINTH B.C. SOIL SCIENCE WORKSHOP

SESSION ONE - The Needs and Expectations of Soil Analysis Users

February 21, 1985 A.M.

G. G. Runka, Session Chairman

NINTH BRITISH COLUMBIA SOIL SCIENCE WORKSHOP

Opening Remarks and Welcome

L.M. Lavkulich, Chairman, B.C. Land Resource Science Lead Committee

On behalf of the Land Resource Science Lead Committee of the British Columbia Agricultural Services Coordinating Committee, I wish to extend a warm welcome to all to this ninth Soil Science Workshop addressing the Role of Soil Analysis in Resource Management. This is a timely topic as soil and foliage analyses become more sophisticated and costly. Also, increasingly private laboratories, in addition to government and university, are playing a greater role in supplying laboratory services. Discussions on soil analysis for resource management decision making is important. Resource managers must make decisions. The kinds of data required to make decisions is varied and complicated. There has to be cooperation and collaboration among laboratories concerning accuracy and precision. There also has to be clearer understanding of what to measure for what objective. Thus dialogue between the requestor and the supplier of laboratory data needs to be strengthened.

The number of analytical techniques are growing and becoming more sophisticated. Equipment is expensive, chemicals and supplies are expensive, thus we must be sure of what data we need and at what accuracy, to keep costs under control. Soil is variable and complex. Plant samples may vary in properties with age and with season. It is important, therefore, that the analyst know the accuracy needed and the appropriate range for measured data. In turn the requestor must know what may be accomplished and the reliability of the data.

Before turning the meeting over to the organizers and session chairmen, I would like to briefly indicate what the Land Resource Science Lead Committee is and how it relates to provincial land resource issues. Agriculture Canada has evolved a rather complex system of advisory committees to focus on regional and national issues. The main committee is called the Canadian Agricultural Services Coordinating Committee or CASCC. Serving on CASCC are seven members representing provincial, or in the case of the Atlantic provinces one Agricultural Services Coordinating Committee (hence BCASCC), the Deans of Agriculture and Veterinary Medicine, representatives from industry, the Agricultural Institute of Canada, etc. Reporting to CASCC is the Canadian Agricultural Research Council (CARC). This organization vets recommendations coming from the CASCC's and from six Canada Committees appointed by CASCC. One of the six

Canada Committees is called the Land Resource Service Committee, on which sits a representative from each province. In British Columbia, BCASCC is chaired by the Deputy Minister of Agriculture and Food. BCASCC appoints members to serve on six Lead Committees. These committees cover Animal Science, Engineering Science, Food Science, Land Resource Science, Plant Science and Social Science. Each of these committees meet once or twice a year to address issues arising from the various regions, identifying problems, setting priorities and screening grant applications for research funded by BCASCC. Of course each Lead Committee may have their own Subcommittees. Thus land resource concerns in British Columbia are fed from the Lead Committee to BCASCC and then ultimately to CASCC.

It is of note that the B.C. Land Resource Science Lead Committee has representation from the Ministries of Agriculture and Food, Environment and Forestry, Agriculture Canada, Environment Canada and the University of British Columbia. We are assured by the Chairman of BCASCC that land resource issues brought forward of a non-agricultural nature are referred to the appropriate agency whether that agency is provincial or federal. Your issues do get through.

At this time I would like to thank the organizing committee, Herb Luttmerding (Chairman), Tim Ballard and Lawrence Lowe for putting together what appears to be an exciting workshop. Also, I wish to thank the Session Chairman and speakers for giving of their time. I am pleased to see the number of students present. Most importantly I wish to thank the audience for coming out in such large numbers, on a rather miserable day. I welcome you all and know the workshop will be a success.

LABORATORY ANALYSIS APPLIED ON AND BEYOND THE FARM

W.A. Herman

The application of an individual's accumulated knowledge in soil science to private practice presents opportunities to stretch one's talents to often unusual circumstances. In offering a soil and plant tissue analytical service to the general public, the doors are opened to meet some of the requirements of farmers, consulting agencies, government agencies, soil management suppliers and hobbyists. The analytical techniques developed in agricultural and forest soil research may be further extended to an improved understanding of soil conditions in situations such as nursery management, hydroponic vegetable propagation, sports field management and landscaping, to name but a few.

The interpretation of soil and/or plant tissue analytical data for agricultural and forestry situations depends greatly on the information derived from past research projects and the skills of the agrologist. The potential benefits may be viewed as improved crop quality, satisfactory yields and maintained or improved soil quality.

A less obvious beneficiary of soil analysis and its interpretation may be the landscape industry. The industry is essentially composed of three agencies involved in each project. The landscape architect often offers little or no formal training in soil science but a capability to envisage the appearance of the finished project in his mind on paper and in reality. The landscape contractor, again speaking generally for the industry, possesses a limited knowledge of soil chemical and physical properties but views soil as a necessary expense to be minimized to insure that the selected plants do not have a medium to set their roots within budget constraints. It may appear inappropriate to speak of soils in terms of chemical properties, physical properties and budgets in the same breath; but this is in fact the situation for landscape contractors. The nurseryman often displays a vast knowledge for preparing high to excessively fertile soils to insure attractive plant appearance in the nursery but offers little appreciation for planting conditions at the landscaping site. The potential for abrasive relations amongst the three parties involved are immense due largely to an insufficient appreciation of the role of soil. A trend now exists within the industry for employment of qualified soil scientists and laboratory backup before a project is started rather than seeking advice after problems are created.

It should be stressed that desirable restrictions for the harvesting of topsoils in British Columbia have forced a new approach for the analysis of soils intended for landscaping purposes. Although a select few landscape contractors offer a keen eye for the permitted collection of soil in areas intended for building construction, the bulk of soil materials utilized for landscaping is a mixture of sand and peat available in copius quantities at relatively low prices. Due to its dark coloration and non-existent structure, the supplier may successfully include in his sales pitch the incorrect usage of buzz words such as

topsoil, loam and friable. In situations of topsoils being legally harvested, the insufficient knowledge of soil classification offered by the bulldozer and scoopshovel operators results in the ultimate stockpile being mainly subsoil excellently mixed with the desired topsoil.

As most installations are completed during the winter months to insure attractive summer viewing, soils are excavated, transported, deposited and worked while in a moisture saturated condition. The final product is a structureless mass of compacted soil components displaying minimized porosity and often zero aeration. In order to avoid criticism of unsightly soil surface preparation and ponded water, a five to ten centimetre depth of bark mulch usually insulates the project from the critics and the warmth of the coming summer sunshine. The combination of cold soil temperatures and poor aeration insures that no self-respecting earthworm will venture into the soil to attempt initiation of structure recovery and drainage improvements.

In an effort to partially correct the previously detailed problems in soil selection and management, the British Columbia Society of Landscape Architects has recently requested a revision of the soil specifications for landscaping. The revisions are currently complete but under review by the B.C.S.L.A.

The revised specifications are designed to accommodate the limited resources of soil suppliers and to upgrade the knowledge of soils for architects and contractors. The specifications are not to be construed as research but rather a vehicle to provide information regarding basic soil physical and chemical properties.

A brief overview of the specifications includes:

a. elimination of the term topsoil unless truly appropriate.

b. analysis of the soil to be done preferably prior to site delivery.

c. analysis of soil materials passing a #10 Tyler Sieve with a visual estimate of proportions of mineral and organic matter not passing the 2 millimetre openings.

d. after total carbon and total nitrogen analyses, the C/N ratio being less than 25. This procedure prevents soil suppliers turning small soil stocks into large stocks with sawdust.

e. % organic matter = % total carbon x 1.724.

f. particle distribution determined by overnight digestion of soil in 1N NaOCl followed by wet sieving through a #270 Tyler sieve. The retained sands are dried in a tared beaker and expressed as a percent of the total starting weight.
100 - (% sand + % O.M.) = % fines. The % fines represent the summation of the % clay and % silt components. The % fine

fraction usually represents less than 20% of landscaping soils. The major concern with fine sized particles in landscaping soils is the plugging of filter fabric pores by either silt or clay sized particles.

g. a 1:1 soil in distilled water mixture often approaches a saturated paste condition for peat and sand mixtures. After measurement of the soil pH, the fluid is utilized to evaluate electrical conductivity. In the event that electrical conductivity exceeds 1.0 mmho/cm, a true saturated paste is evaluated.

h. recommend use of time release fertilizers with incorporated micronutrients to accommodate the low nutrient retention of sand and large peat fragments.

i. recommend postponement of bark mulch application until soil has had an opportunity to develop cracks due to drying.

In closing, a great deal of animosity has been reduced in the landscaping industry through application of soil science principles. It may be of value to us as soil scientists to be informed that many of the components of the landscaping soils which we may be viewing in the landscaping soils of the site of Expo 86 and along the ALRT route are currently located at the bottom of the Fraser River. The ultimate mixture presented for our approval, of at least the vegetation, will be devoid of the influence of topography, climate, vegetation and time factors in its genesis and of a questionable parent material. It would appear appropriate to substitute the term "soil preparation" for topsoil in the specifications customarily utilized in the landscaping terminology.

HORTICULTURAL REQUIREMENTS AND INTERPRETATIONS

BY BRIAN E. MAUZA

As a horticulturist dealing primarily with the greenhouse industry I utilize laboratory analysis of soil, water and plant tissue as a diagnostic tool as well as a management tool. The greenhouse industry is somewhat unique in the fact that it has moved away from soil-based media to non-soil media for plant production. As a result, elements and their amounts in nutrient solutions are of greater use in day to day work.

As a diagnostic tool I require water analysis to (predict) element levels in irrigation water prior to calculating the composition of a nutrient solution for soilless cultures. As well the pH and alkalinity are required to bring the solution into the desirable range for optimum plant growth. With pH, in fact we recognize that the desirable pH range in soilless culture systems is in the 5.3 - 5.7 range rather than the 6.3 - 6.8 range for soil systems. As a diagnostic tool I use these analyses to indicate probable elemental imbalances in media or in propriatory mixes which may or are suspected of causing problems for crop growth. Monitoring manganese levels in fir and hemlock sawdust is recommended prior to cropping long English cucumbers. Toxic levels are known to accumulate in these woods and long English cucumbers are very sensitive. As a diagnostic tool I use tissue and solution analyses to evaluate the effects to plants of changes in the elemental composition of a fertilizer program.

As a management tool growers also use analyses to monitor the progress of their crop and to document the plant's appearance. A specific example would be the management of potassium and calcium nutrition at the commencement of harvesting hothouse tomatoes.

From an extension standpoint we need to have a complete picture of any operation prior to issuing a recommendation based on an analysis. Such information as previous crop history, age of crop, environmental conditions, presence of disease or insect stress, types of fertilizers used and nutrient solution preparation often are required before accurate interpretations of soil, tissue or water analyses are issued.

I might stress the need for repetitive samples preferrably bi-weekly to develop trends. These trends should be integrated with the previous stated list of information required.

Another requirement for our industry is to establish a broader base of crop responses in soilless media and to establish what analysis levels accurately reflect plant requirements.

Lime requirements for pH correction in potting mixes are still based on old formulas not necessarily crop duration.

Our industry places a lot of emphasis on moisture holding capacity or aeration of potting mixes but this is not reflected in regular analyses either.

SOIL CHEMICAL DATA REQUIREMENTS

FOR FORESTRY INTERPRETATIONS

Terence Lewis

Soil chemical data requirements for forestry involve two areas of interest, namely-

1. silvicultural, the growing of tree crops, and

2. assessments of the impact of treatments on the soil and the wider environment.

SILVICULTURE

One of the aims of silviculture is to provide growing conditions as close to optimum as is feasible under certain environmental and economic constraints. Edaphic conditions, specifically soil chemical conditions, are a key part of the environmental complex that affects tree growth. The silviculturist is primarily interested in the major and minor nutrient elements and the physical-chemical-microbiological environment that determines their availability. In this regard, he has much in common with the agriculturist and horticulturist.

As a performance-oriented manager, the key concern of the silviculturist is the availability to the forest crop of nutrients, as well as energy and water. The question of availability raises two concerns of which both the forester and soil chemist should be aware, namely -

1. some significant distinctions between many agricultural and forest soils, and,

2. that soil chemical analysis has largely been derived from agriculture.

Agriculture versus Forest Ecosystems

Historically we have tended to use the most naturally fertile soils for agriculture, at least in the Temperate zones. These include the alluvial and deltaic soils and the chernozemic soils of the steppes of both Eurasia and North America. (This is a luxury often not afforded in Tropical regions.) Forests tend to be relegated to and managed on soils of average to poor fertility. Consequently "agricultural soils" usually have relatively larger stocks of nutrients. These stocks are regularly and frequently reduced by cropping, with such withdrawals of nutrient capital being replaced as necessary by various cultural practises - fertilizing, manuring, rotating of crops with legumes ... This might be seen as essentially an input/output budget.

Forest soils, on the contrary, usually have relatively small stocks of nutrients, particularly of available nutrients. The productivity of forests is in large part supported by the efficient cycling of a relatively small pool of available elements. At any point in time, a large proportion of nutrients is tied up in biomass and organic matter. This is most pronounced in our extensive Boreal, Sub-Boreal and Subalpine forests where soil temperature limits organic matter turnover rates (typically Hemimor humus forms). It is also true in much of our very productive Coastal forests (typically Humimors). Forest soil management therefore is in large part soil organic matter management. Often the most realistic strategy for the silviculturist is to act to fine-tune the various nutrient cycling processes rather than trying to add significantly to the stock of available nutrients. This may involve physical treatments such as scarification and prescribed burning and stand manipulations that influence soil climate such as spacing and thinning as well as fertilizer amendments.

Methodology

Analytical methods have historically been devised for agricultural purposes and applied, often without modification, to forest soils. This is likely appropriate for items such as pH, carbonate content and organic matter content. As for cation exchange capacity and exchangeable cations, I have often wondered how to interpret ammonium acetate - pH 7.0 data for a soil that has a pH of 5.0 to 5.5 and a highly pH-dependent exchange capacity? When dealing with soils where the key to availability is turnover of organic matter, it is a long journey in both the mind and the soil from Kjeldahl nitrogen or Bray phosphorus to knowing just what amount of N or P is actually available to the forest crop.

What then can be done to surmount known or suspected deficiencies in soil chemical data? In my own work over the last ten years, I have increasingly looked more and more to foliar analysis for forestry interpretations. Performance, in the sense of what actually is in the tree, is after all the ultimate result of availability. Since analyses of both soil and foliage is expensive, it is necessary to optimize data collection efforts. Although it may be tempting for foresters and forest soil scientists to move to foliar analysis, I would recommend a mix of soil and foliar analysis in order to build up a broader understanding of the relationships between forest soils and the forest.

IMPACT ASSESSMENT

The protection of forest crops from insects and disease and the control of undesirable competing vegetation at times requires the use of various pesticides and herbicides. For example, in our Coastal forests, the invasion by red alder (Alnus rubra) of sites of superior fertility and productivity is the major contributor to NSR (not sufficiently restocked) and NCC (non-commercial cover) types.

If we are going to use chemical formulations for control, then we must know what is the ultimate fate of these chemicals and their degradation products. Foresters will need soil and water chemists to identify the pathways and fate of these materials. This problem does not have so great a magnitude as in agriculture or horticulture since the number of chemicals registered for use in forestry is more limited. At this time only four herbicides are registered (2-4-D amine, Roundup, Velpar for ground application and Krenite for roadside use). Furthermore, the trend in pesticides appears to be toward biological (eg. Bacillus thuringiensis formulations) rather than chemical formulations.

CHEMICAL ATTRIBUTES OF SOILS IN MAKING ENVIRONMENTAL INTERPRETATIONS

J.H. Wiens

Waste Management Branch
B.C. Ministry of Environment

INTRODUCTION

It is now commonly recognized that soils information is valuable and often essential for many environmentally related resource management decisions. Soil scientists have stated this for years. Government agencies and consulting firms are appreciating this and are employing soil specialists. At this workshop however, I do not need to spend time convincing you of the vital role of good soils information. I will assume I am speaking to those already convinced.

It is sometimes stated that a measure of the maturity of a science is the degree to which it can be quantified. In other words, if attributes can be measured, and relationships between variables can be described and manipulated mathematically, then a science has become of age. I am sure we recognize the difficulties of pressing this argument too far. However, soil science as a discipline has been advancing and increased quantification has played a part in soil physics, soil chemistry and fertility, soil taxonomy etc. In measuring and interpreting soils information for environmentally related purposes, advances have also been made but much further effort is still required.

The theme of this workshop is soil analysis. My objectives for this paper, therefore are:

- to identify some environmental issues, problems or areas in which soil analysis and interpretations are being used or will be required;
- to emphasize the need for asking critical questions so the types of soil analysis required will be done to meet the objectives;
- to define soil attributes and the nature of analyses needed for some environmental interpretations;
- to discuss some needs for and illustrate interpretations of soil analysis data for environmental purposes.

Primarily, I am to discuss chemical attributes of soils. I will do this but will make reference to physical analysis in some cases. My purpose in doing so will be to emphasize that by their nature environmental interpretations - answers to soil-related environmental questions - will not be adequate if relationships between chemical, physical and perhaps mineralogical or biological properties are not recognized and accounted for.

CONTEXT OF SOIL ANALYSIS

To put soil analysis and interpretation, and my objectives for this paper in a context, Figure 1 is presented. Soil analysis is the focus of the diagram because it is the theme of this workshop. The figure is not necessarily complete nor the best way of portraying the relationships. It does make several points which will be expanded later. Briefly, to be noted is:

1. Soil analysis and interpretation typically follow or should follow from:

   - an enviromental issue that is raised and needs to be addressed or a proposed development project with expected impacts;

   - identification of problems to be addressed and the definition of objectives for studies to be undertaken;

   - posing of some critical questions in order to determine what soil attributes should be analyzed for and more particularly what methods should be used.

2. A number of associated considerations and factors need to be taken into account when planning soil analysis for environmental interpretations. These include for example:

   - adequate sampling
   - decisions on accuracy and precision
   - planning for statistical analysis

3. Interpretation of results of analysis is a most critical activity. It brings the results of analysis to bear on the defined objectives and should result in answers to the critical questions posed.

It is my view that the right environmental questions often are not asked. This may mean that inadequate or inappropriate allocation of resources is made to soil analysis. Further, I believe that even when considerable resources are allocated to analysis, interpretation of results for environmental purposes often is inadequate.

ENVIRONMENTAL ISSUES AND PROBLEM AREAS

A wide variety of environmental issues and problems areas have benefited or could benefit from soil analysis and interpretation. The following is a list of a few:

1) Effluent disposal to land by spray irrigation or flooding.

2) Municipal waste treatment and septic tank sludge disposal to land.

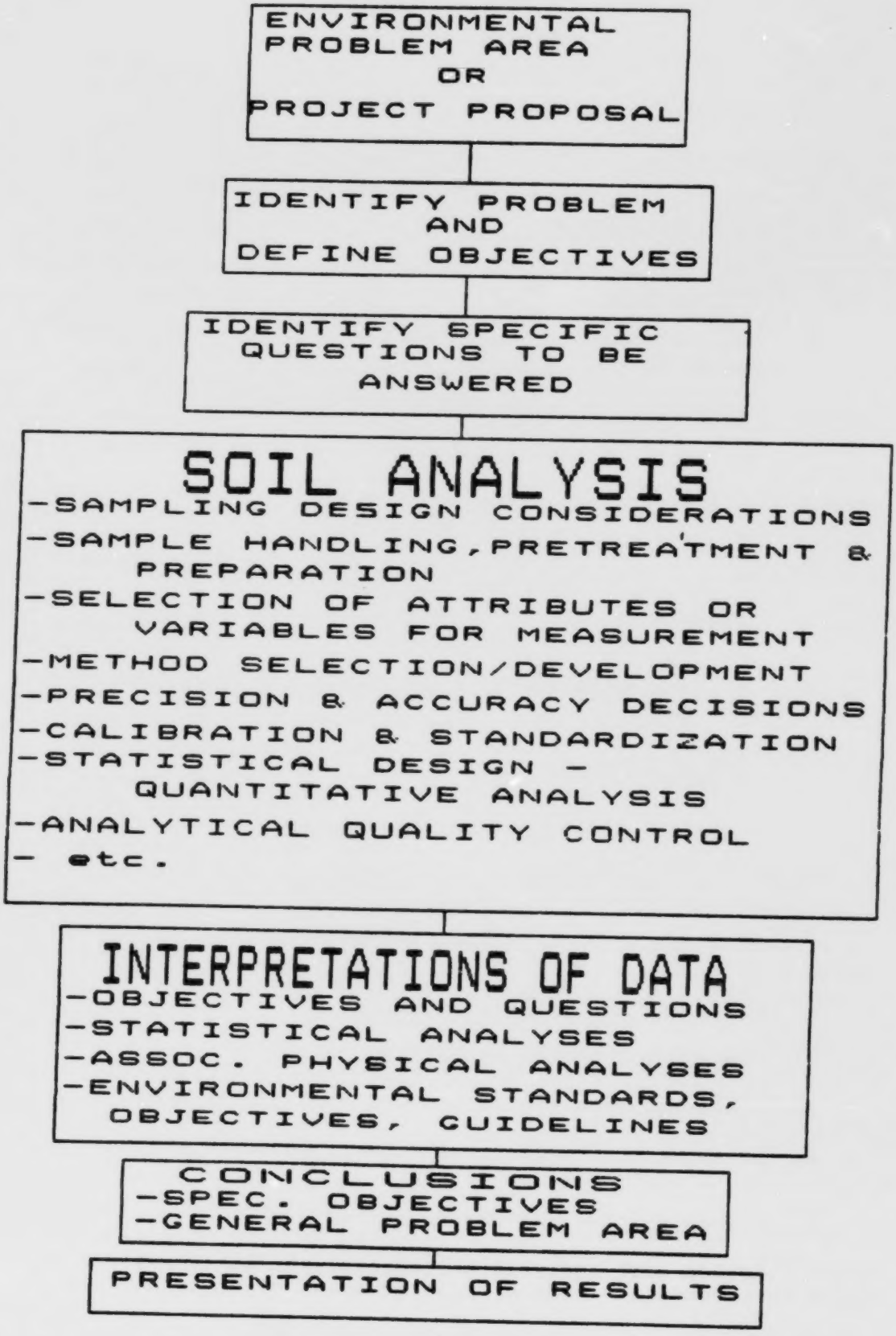


Figure 1. Soil Analysis in Context

3) Subsurface disposal of septic tank effluent.

4) Disposal of gas and oil well drifting fluids to land.

5) Terrestrial impacts of acid precipitation, sulphur dust or fertilization.

6) Soil contamination by trace elements from industrial air emissions (e.g. Pb, Zn Cu, Cd, F).

7) Soil accumulations of lead from automobile exhaust emissions.

8) Reclamation of mine spoils and tailings.

9) Reclamation/rehabilitation of municipal landfills.

10) Landfarming and perched bed treatment of toxic wastes.

11) Groundwater contamination from forest nursery or agricultural applications of fertilizers and pesticides.

12) Dredge spoil and construction impacts on soil properties and crop productivity.

13) Soil contamination from spills of toxic chemicals (e.g. PCP, PCB).

14) Role of soils in diffuse or non-point source runoff to water.

15) Long-term accumulation of pesticides in soils.

16) Irrigation water quality impacts on soil quality and crop productivity.

It will be recognized that these issues relate to such broad areas as:

1) Solid and liquid waste disposal.

2) Atmospheric source deposition.

3) Disturbed site reclamation.

4) Environmental impacts of forest, agricultural, mining, and other industrial practices.

5) Transportation and construction.

Objectives for soil analysis and interpretation in any one of the above environmental issue or problem areas might relate to:

1) Charactertization of basic properties.

2) Monitoring background levels and changes of soil components.

3) Establishing criteria and objectives for application rates or maximum accumulations of apotential contaminant.

4) Developing predictive relationships between difficult to measure and easily measured attributes or indicators.

5) Defining pathways and rates of movement through or losses from soils (e.g. contaminants, nutrients).

In the broad sense of the term all these are objectives of environmental research or scientific activity for the purpose of maintaining, restoring or improving the environment or predicting changes in it.

For each of the environmental issues or problem areas, a wide range of specific questions could be posed for answering with soil analysis and interpretation. A definition of the objectives whether one of the above or some other serves to narrow the range of questions. This specification of questions to be answered, guided by objectives is highly desirable if soil analysis and interpretation are to be most useful.

ENVIRONMENTAL QUESTIONS TO DIRECT SOIL ANALYSIS

A few examples will illustrate how objectives and questions might direct decisions on soil analysis. A summary will then be given of attributes which might be measured for a range of other environmental issues and objectives.

Soil Contamination from Air Emissions

Industrial air emissions typically have some concentration of potential environmental contaminants. Even best available control technology will not prevent this entirely. Mining, milling and smelting operations may have point or fugitive emissions of gaseous and particulate materials such as SO_2, F, Cu, Zn, Pb, Cd etc. Kraft pulp mills may have reduced sulphur compounds such as H_2S and mercaptans. Sour gas processing plants produce SO_2, CO_2 and H_2 and sulphur dust in the process of removing H_2S. The list goes on. There may be consequences to the surrounding terrestrial environment. Soil is to be analysed. Where does one start?

Assuming for example purposes that we are dealing with the issue of smelter emissions, possible objectives of soil analysis might be:

1) To establish whether detectable increases over background of trace metals in soil in the area of the smelter have occurred.

2) To determine the extent to which increased trace metals in soil in the area of the smelter have occurred.

3) To determine whether trace metals in soil in the area of the smelter are likely to affect vegetation.

4) To establish guidelines or objectives for soil accumulation of trace metals.

You will recognize the increasing complexity in these alternate objectives. You will also recognize the whole host of questions that are raised regarding proper sampling in relation to:

- direction and distance of emissions fallout
- homogeneity of soils and soil parent meterials
- other possible influencing sources (e.g. transportation, other point sources)

Assuming those aspects are handled by a satisfactory sampling design, what about the analytical aspects? What critical questions must be asked? Some of these might be as follows:

1) What chemical elements are likely to be emitted either in stack or fugitive emissions and therefore deposited on the soil?

2) What elements are not likely to be emitted but are present in soils, and could be used as a check, for example in ratio calculations?

3) Is total elemental analysis either desirable or necessary, or is some measure of a more readily soluble form (e.g. weak acid or complexing agent extractable) more appropriate to the objective?

4) What detection limits are required and therefore what quantitative analytical methods are available, and which must be excluded?

5) Do any of the expected contaminants or any normal soil levels constitute an interference problem, thus affecting the choice of analytical method?

6) Are there any potential aspects of the analytical method that could result in losses (e.g. volatilization) or measurement inefficiency (e.g. incomplete atomization) which would result in inaccurate results?

7) In what units should results be reported?

These are some of the questions. What about answers?

In order to answer some of the questions, let us assume the objectives for the proposed project relate to vegetation impacts

and development of guidelines for soil accumulation. We will assume the case in point is a sulphide smelter and emissions are likely to be Cu, Zn, Pb, Cd, As and some SO_2. Pertinent points to answer some of the above questions are:

1) Total elemental analysis alone is inadequate. A measure of a more available form is required since vegetation impact evaluation is part of the objective.

2) The element tin (Sn) or perhaps chromium (Cr) might be analysed for as a check and used for ratio calculations.

3) Detection limits should be at least 1 ppm for all other elements and at least 0.01 ppm for cadium given the ranges and mean values of elements in soils reported in the literature.

4) Although units for reportig laboratory analysis results will probably be ppm or µg/g, proper interpretation of the data will require converting data to a mass per unit volume basis with the aid of bulk density information. Unit area deposition rates can then be calculated.

5) Interference between elements, and losses or inefficiencies in measurement depend on instrumentation and measurement method. Their consideration is dependent on method selection.

Disposal of Gas and Oil Well Drilling Fluids to Land

Exploration drilling of wells for oil and/or gas is common particularly in northern B.C. You may be familiar with this practice and its environmental implications. Drilling fluids of various formulations are used to lubricate and cool drill bits, seal geologic strata, and propel solids to the surface. These fluids are recirculated from pits or sumps at the drill site. On completion of a job these fluids must be removed or disposed of. Land discharge is a preferred method. However, alkalis, organics, trace metals and high soluble salt contents can have impacts on soils and vegetation.

Soil analysis might be undertaken in relation to this problem for several purposes. These might include:

1) To establish basic characteristics of a soil to allow assessment of potential for acceptance of the fluids or for adverse impacts.

2) To determine soil levels of various known or suspected components of drilling muds associated with observed crop or soil physical property effects.

3) To establish soil characteristics associated with experimental applications of drilling muds on field plots or indoors.

4) To assist in establishing criteria for disposal of drilling fluids on land.

5) To guide the selection of ammendments for reclamation of disposal areas.

You will recognize again that chemical analysis of soils without associated vegetation or soil physical property analysis is likely to present an inadequate picture.

Let us assume the objective in this case is not to conduct controlled experiments on application rates of drilling fluids or their components on plant growth. Rather, let us assume a field study is planned of a number of different, older disposal areas. An assessment is desired of soil conditions and problems, and probable effects on plant growth.

Some questions which might be asked, to direct soil analysis are:

1) What type of drilling muds were used (e.g. high KCl, NaOH, $Ca(OH)_2$, $BaSO_4$, lignosulphonate, lignite, diesel fuel)?

2) What application rates were used at each site?

3) Were other additives or amendments applied along with the drilling fluids?

4) What trace metals are suspected contaminants (e.g. Cr, Cd, Zn, Pb)?

5) Can the assessment be divided into several phases with results of the first phase, an overview study, directing the design of the second, more detailed phase?

In this case, if it is assumed that records of disposal at these sites are not well kept, a preliminary overview would seem prudent. Along with the soil analysis, observations and perhaps some quantification of vegetation growth might be made. Soil analysis for the following parameters might be undertaken:

- pH
- CEC
- organic matter content
- range of trace metals (e.g. Cr, Cd, Zn, Pb)
- exchangeable bases
- electrical conductivity (saturated paste extract)

In the case of trace metals, an analytical method giving concurrent readings on a variety of elements might be used in the preliminary overview.

Once an initial, survey type of analytical study has been carried out, a more detailed, statistically designed study might be undertaken. Easily extractable metals (e.g. weak acid or complexing agent) could be determined, exchangeable Na percent (E.S.P.) calculated etc. In the event that poor revegetation is observed but other inorganic parameters do not indicate an apparent explanation, selected analysis for suspected organics might also be undertaken.

Summary - Environmental Issues, Objectives and Soil Analysis

Any one of a wide range of case examples - environmental issues involving soil analysis - could be analyzed. I would just like to summarize for a range of issues, possible objectives for studies involving soil analysis, soil attributes of probable importance, and variables for which analysis might be done. This summary is provided in Table 1.

INTERPRETATION OF CHEMICAL ATTRIBUTES

It has been indicated earlier in this paper that often critical environmental questions are not asked. This may result in inadequate or inappropriate soil analysis. It has also been indicated that interpretation of data is frequently inadequate. Interpretation of data is the topic of this section of the paper.

Interpretation in Context - Objectives and Questions

Objectives and terms of reference initially are often ill defined for investigations of environmental problem areas involving soil analysis. A project proponent who may be the client of a consultant or a government agency involved in resource or environmental management often will not know immediately and clearly, what it is they want from an investigation. It is therefore essential for cost-effective soil analysis that objectives and questions to be answered are explored and agreed upon. It is even more essential for interpretation of data that these objectives and questions are clearly defined.

Soil chemical analysis is often only one component of a larger study. The context of soil chemical analysis is therefore important for interpretation. What conclusions are required from soil analysis as input to other components? What overall conclusions on the environmental problem area generally are to be made?

Routinely Measured Soil Attributes

Research or contract proposals and reports involving soil chemical analysis most often call for, or report on routine analyses such as pH, cation exchange capacity, exchangeable bases, Kjeldahl nitrogen, organic matter content, iron and aluminum oxides etc. As soil scientists we may know why they are requested or reported on, but does the client or the manager in the resource management agency? We know that general inferences about trace metal

TABLE 1. Environmental Problem Areas Involving Soil Analysis - Objectives, Attributes and Measurement Variables

Environmental Problem Areas	Objectives for Studies Involving Soil Analysis	Soil Chemical Attributes & Measurement Variables*
1. Effluent Disposal to Land.	1. Assess soil suitability for feasibility and design. 2. Predict long-term soil changes and groundwater impact. 3. Monitor soil and groundwater build-up of contaminants, if any. 4. Optimize agronomic management.	pH; CEC; exch. bases; TKN; PO_4^{-2}; S; PO_4^{-2}; adsorp. cap.; trace metals; Elec. Cond.; S.A.R.; E.S.P.; B; Free CO_3^{-}; Fe & Al oxides.
2. Municipal and Septic Tank Sludge Disposal.	1. Develop application rate criteria 2. Monitor build-up of critical constituent, (e.g. trace metals) 3. Study crop, microorganism etc. response to different types and rates of sludge. 4. Optimize agronomic management.	pH; CEC; exch. bases; TKN; PO_4^{-2}; trace metals (Cd, Zn, Cu, Ni, Pb, Cr, Co, Mo, Hg); E.C.; B.
3. Septic Tank Effluent - Subsurface Ground Disposal.	1. Assess soil suitability and predict ground impact. 2. Assess effluent plume movement and groundwater contamination, if any. 3. Determine causes of system failure.	pH; CEC; PO_4^{-2}; adsorp. cap.; E.C.; Cl; NH_4^{+}; Fe & Al oxides.
4. Disposal - Gas & Oil well drilling fluids.	1. Establish basic characteristics and soil suitability. 2. Develop application rate criteria. 3. Monitor soil and crop response to diff. levels and types of drilling mud. 4. Monitor application rates (regulatory). 5. Guide reclamation of disposal areas.	pH; CEC; exch. bases; S; Ba; E.C.; S.A.R.; E.S.P. trace metals (Cr, Pb, Zn, Cu, Cd, Hg); O.M.
5. Acid Precipitation - Terrestrial Impacts.	1. Develop soil "sensitivity" criteria. 2. Determine soil "sensitivity". 3. Research soil changes due to acid ppt. 4. Develop deposition rate criteria. 5. Monitor soil changes, if any, due to acid ppt. 6. Assess soil changes related to vegetation impacts. 7. Evaluate relative impacts of acid ppt. vs. acidification due to other sources (e.g. fertilization, N-fixation, weathering).	pH; CEC; exch. bases; buffer titration curve; sol./exch. Al, Mn, Fe; free carbonates; SO_4 adsorp.; S; lime requirement.

TABLE 1. Environmental Problem Areas Involving Soil Analysis - Objectives, Attributes and Measurement Variables (cont'd)

Environmental Problem Areas	Objectives for Studies Involving Soil Analysis	Soil Chemical Attributes & Measurement Variables*
6. Soil contamination - industrial air sources.	1. Establish if detectable increases of soil components (e.g.trace metals) over background have occurred. 2. Determine distribution and extent of increases. 3. Determine effects on vegetation (e.g. growth or trace metal levels). 4. Establish guidelines for contaminant build-up.	pH; CEC; exch. bases; S; O.M.; trace metals. (analysis depend on industrial processes and type of emissions).
7. Automobile emissions effect on soil (e.g. lead accumulation).	1. Determine distribution pattern of Pb. 2. Investigate the relationship of Pb accumulation in soils to traffic patterns and density. 3. Determining maximum build-up of Pb in soil. 4. Assessing the availability of Pb and uptake by plants.	pH; CEC; O.M.; Pb and other trace metals, total and weak acid or complexing agent extractable.
8. Reclamation of mine spoils and tailings.	1. Establish basic characteristics and limiting factors of materials. 2. Determine amendments needed. 3. Determine potentials for leachates especially with reclamation activities (e.g. irrigation, fertilization).	pH; CEC; exch. bases; total or titrable acidity; total & available trace metals; available P; TKN; O.M.
9. Land farming and perched bed treatment of toxic wastes.	1. Assess soil suitability for in place use or as a treatment medium. 2. Characterize soil for retention effectiveness and capacity of various components (e.g. organics, trace metals). 3. Monitor efficiency of removal of toxic constituents from waste stream by analysis of soil build-up in association with inflow and outflow.	pH; CEC; exch. bases; PO_4^{-3}; and SO_4 adsorption cap.; trace metal adsorption cap.; Fe & Al oxides; free carbonates.

TABLE 1. Environmental Problem Areas Involving Soil Analysis - Objectives, Attributes and Measurement Variables (cont'd)

Environmental Problem Areas	Objectives for Studies Involving Soil Analysis	Soil Chemical Attributes & Measurement Variables[a]
10. Groundwater contamination from agricultural practices and intensive forestry (e.g. nurseries).	1. Establish basic soil characteristics and assess potential for leachate losses. 2. Monitor soil build-up of potential contaminants. 3. Monitor loss of nutrients, pesticides etc. below a specified soil depth. 4. Develop predictive relationships between soil properties and chemical movements.	pH; CEC; exch. bases; P; PO_4^{-3}; Adsorp. cap.; NO_3-N; pesticides (analysis depend on pesticides used).
11. Dredge spoil and construction impacts on soil properties and crop productivity.	1. Establish basic properties and limiting factors of spoil. 2. Determine toxic components, if any, in dredge spoil. 3. Optimise agronomic management.	pH; CEC; exch. bases; available P; available trace metals; lime requirements.
12. Soil contamination by spills of toxic chemicals.	1. Assess the extent of contamination to aid costing and process of clean-up. 2. Assess soil levels, probable toxicities, and potential for in place treatment and reclamation. 3. Monitoring progress/completion of clean-up.	pH; CEC; O.M.; analysis for contaminants involved
13. Long-term accumulation of pesticides in soils.	1. Assess build-up of pesticides. 2. Develop predictive relationships between build-up/breakdown and soil chemical properties. 3. Assess soil conditions in relation to pesticide effectiveness.	pH; CEC; O.M.; Fe & Al oxides; anion exch. cap.; analysis for pesticides and derivatives.
14. Reclamation/rehabilitation of municipal landfills.	1. Evaluate basic properties of in place fill and cover material for revegetation. 2. Evaluate suitability of alternate sources of cover material for reclamation. 3. Determine amendments needed for establishing and sustaining cover. 4. Determine nature and extent of upward migration of contaminants from waste materials below.	pH; CEC; exch. bases; avail. P; lime requirement.

TABLE 1. Environmental Problem Areas Involving Soil Analysis - Objectives, Attributes and Measurement Variables (cont'd)

Environmental Problem Areas	Objectives for Studies Involving Soil Analysis	Soil Chemical Attributes & Measurement Variables*
15. Role of soils in non-point or diffuse source runoff to water.	1. Estimate movements of nutrients through surface and subsurface pathways to receiving waters. 2. Evaluate nutrient transmission through soils and develop quantitative measures describing attenuation. 3. Develop predictive measures for sediment attached losses of nutrients, pesticides, etc.	pH; CEC; exch. bases; P adsorption/release.

* - General indication of analysis often involved. Attributes may be added or deleted depending on objectives. Methods may vary (e.g. $pH(H_2O)$; $pH(CaCl_2)$; CEC-NH_4OAc or pH dependent).
- Analysis of physical properties in association with chemical analysis is often required. Such attributes as texture and hydraulic conductivity are particularly important.

solubility, adsorption of phosphorus, leachate quality, or suitability of soil materials for reclamation can be derived from this data. However, it is my experience that once these analyses are called for or reported on, their justification often is not given and they do not become an integral part of soil analysis data interpretation.

It was noted earlier that maturity of a science comes with quantification. Maturity in environmental interpretation of soil chemical analysis data may come as we vigorously, perhaps boldly, use these routinely analysed attributes in predictive relationships or as stratifying variables. Their expense must be justified by their use in interpretations to meet the objectives.

Statistical Design and Analysis

Later papers in this workshop will deal specifically with soil variability, probability assessment and other topics involving statistics. Therefore only a few comments will be made here.

Rigorous statistical design and analysis of soil chemical attributes unfortunately are not used routinely in environmental investigations and interpretations. Costs and time constraints are most frequently cited as reasons. Such reasons are valid but must be weighed against constraints on useful interpretations and conclusions. It is entirely possible that evaluations based on some reasonable assumptions and first principles of soil chemistry, and judicious sampling and analysis may give more accurate, useful interpretations than evaluations based on a study where statistical design is a focus. Ideally, statistical considerations are complementary to other aspects of any study.

Joint Use of Chemical, Physical & Mineralogical Soil Analysis Data

Many environmental problems involving soil analysis simply cannot be adequately addressed by limiting analysis and interpretations to chemistry or physics, or mineralogy, or biology. Joint consideration of one or more of these areas is required. A few examples may illustrate the point:

1. Evaluation of the operation and impacts of a sewage treatment lagoon with no surface discharge and perhaps operating in tandem with an evapotranspiration bed, requires consideration of soil hydraulic conductivity, evaporation and evapotranspiration rates etc., as well as phosphorus adsorption capabilities.

2. Evaluation of soil contamination and accumulation rates of trace metals in relation to air emission rates from industrial stacks or from automobiles requires bulk density measurement to allow expression of data on a mass per volume and deposition per unit area basis.

Models, Assumption and Prediction

Perhaps you have had the same experiences I have had. Literature has been reviewed, soil chemical data have been assessed, and conclusions with limiting conditions have been stated. A client or manager, on reviewing the data comes back with questions such as:

- Will this waste application contaminate the groundwater?
- Is the contaminant application harmful to plants?
- What is the effective life of the adsorption field?
- Will phosphorus leave the site and eutrophy the lake?
- To what extent will the soil be acidified within 15 years if the present rate of SO_4 deposition continues?
- How long will it take for the pesticide to reach the watertable?

Data has been interpreted but it has not addressed the ultimate questions requiring answers for management decisions. We may state that the data does not allow such answers or that there are too many unknown variables. However, a decision will be made. An opinion on, or answer to one of the above questions may be extracted in verbal discussion. Is this adequate or the best solution, or should another approach be used?

In the case of some of the examples above, it may have been better as part of the interpretation itself to make some assumptions, state the risks, and make some predictions. Sometimes simple predictive models, or simply systematic calculation procedures can be followed to a logical conclusion. Reluctance to do so may simply mean that another, less qualified person will do so but in a less satisfactory fashion. Decisions will always be made under uncertainty.

Readily accessible tools such as powerful desktop and portable personal computers with spreadsheets and other applications software have made systematic calculations and even dynamic modelling available to any serious soil scientist. These must be used to their full potential.

SUMMARY

The importance of a context for soil chemical analysis and interpretation has been emphasized. Definition of study objectives and identification of critical questions to be answered provides this context.

A variety of environmental problem areas have been identified. Possible objectives and soil chemical attributes for analysis have been noted. Several problem areas have been discussed as specific examples.

Finally, several limitations and deficiencies common to interpretation of soil chemical analysis data have been discussed. Encouragement is given to use powerful, available tools in environmental interpretations.

CHEMICAL DATA IN SOIL TAXONOMY

L.M. Lavkulich
Department of Soil Science, University of British Columbia

Introduction

With the possible exception of soil texture, soil taxonomies have relied heavily on soil chemical data. The three most common parameters have been pH, organic matter, and nitrogen. The first may be measured both in the field and in the laboratory; the second two require laboratory estimates. These parameters were chosen as they were relatively easy to measure and had significance to the growth of higher plants. As taxonomies evolved, chemical parameters continued to be used and became more sophisiticated. There was, and still is, a cry from the field pedologist to keep the chemical parameter measurements simple and to choose those that can be applied in the field to separate different soils. However, as taxonomies became more complex and more taxa were recognized, the laboratory became increasingly important. In the past few decades there have probably been more techniques developed to attempt to characterize amorphous inorganic constituents for soil taxonomy than any other parameter. This is particularly so for criteria of the podzolic B horizon and for the recognition of the presence of volcanic ash and its weathering products. This presentation will assume that soil samples have been correctly taken for the object of soil taxonomy, whether they are taken randomly, composited, or are from a modal pedon. It has been my experience, borne out by the literature, that our measurement techniques are more precise than the variability in soil chemical properties in the field. The following discussion will deal with chemical parameters used in soil taxonomy, mainly in the Canadian context, and will address both field and laboratory procedures.

Field Measurements

The most obvious soil chemical parameter measured in the field is soil pH. The accuracy of the measurement can be questioned as it usually involves dyes that take different colors depending on the pH. The main problem is, however, that the field measurement of pH is dependent on moisture content and, even, time of year.

In classification of organic soils, one procedure can be done in the field, that is the pyrophosphate index. In this method, Na-pyrophosphate is mixed with moist organic material, allowed to stand overnight, then chromatographic paper is allowed to contact the mixture. The color value and chroma are read on the strip. The pyrophosphate index is the difference between the Munsell value and chroma. This is a useful technique to evaluate state of decomposition of the organic matter in separating Fibrisols, Mesosols, and Humisols.

The presence of allophanes or amorphous aluminosilicates in soils has received widespread attention. Fieldes and Perrott (1966) developed a field

technique to estimate these amorphous constituents. Because of the large pH-dependent charge on these materials, reacting the soil with 1 M NaF the pH rises to values in excess of pH 8. Wada and Harward (1974) found that the technique was useful for estimating poorly ordered Al compounds in spodosols (podzols). Since the technique is simple to use it has been proposed for estimating sesquioxides in podzolic B horizons. The technique, however, has too wide a spectrum of reaction so it has not been adopted, not even for the proposed new Order in Soil Taxonomy, Andisols.

Staff of the National Soil Survey Laboratory of the U.S.D.A. in Lincoln, Nebraska have been developing field tests for diagnostic horizons. These techniques and others have been tested in Canada by Schuppli and McKeague (1984). The field tests include 4 N KOH extraction, neutralization with HCl, addition of KF, and titration of the OH^- released with HCl and measuring the color difference of a pH 10 extract before and after flocculation. Colors are expressed in liter-platinum units per gram. Proposed criteria for spodic (podzolic-B) horizons are

Humic color > 10 L-pcu/g

KOH Al $\geq$ 0.7%

B/A Al ratio > 2

Schnitzer and Wright (1957) developed a procedure for extracting amorphous material by the use of HCl-HF. This can be done in the field in a screw cap polyethylene bottle. The color of the extract is measured on an eight-point scale from 1 (colorless), 4 (yellow - approximately 2.5 to 7.5/6), to 8 (dark brown). Proposed criterion for podzolic-B horizons is $\geq$ 4, while $\leq$ 4 is not podzolic. Schuppli and McKeague (1984) also measured the color extract from soils treated with acid ammonium oxalate and the same criterion applied as for the HCl-HF extraction. The results were generally mixed when applied to 64 soil samples from nine provinces and the Northwest Territories. They concluded that the HCl-HF test showed the greatest promise, but laboratory back-up was still recommended.

Laboratory Measurements

Increasingly over the past two decades, the laboratory has become important in soil taxonomy. The definitive criteria that have been developed to separate different taxa have become more critical. Some may argue that the definitive criteria are too specific considering the variability of soils, the problems of sample location, and the problems of sampling.

In general carbon and nitrogen analyses have been standardized and there are few problems. Occasionally, with woody samples, the Walkley-Black method may under-estimate the total carbon and, in calcareous samples, induction furnace techniques may over-estimate total carbon.

Similarly, the standardization of measuring soil pH in 0.01 M $CaCl_2$ is fraught with few problems. Soil pH is important in separating soils of the Brunisolic Order of soils and, of course, is used as differential at the soil family level.

Another measurement used to differentiate various taxa for soils is electrical conductivity. This measurement has been around for many years and the procedure has not changed. The magic number of 4 mS/cm dividing saline soils from non-saline seems to be well established.

Cation exchange capacity and associated base saturation are parameters that are used in soil taxonomy. The standard 1 N NH_4OAc method appears to be well accepted and the method is fairly precise. This is not the case in some soils of older landscapes than those found in Canada.

Again, much emphasis has been placed on estimating amorphous materials in soils. In Canada this has been associated with definition of the podzolic-B horizon and, to a more limited extent, in criteria for a gleysolic Bgf horizon. The two currently practised methods are Na-pyrophosphate extraction of sesquioxides and citrate-bicarbonate-dithionite.

Na-pyrophosphate extraction procedures have been available for many years and are used extensively for extraction of organic matter in soils. In 1978 it was accepted as the method for estimating iron and aluminum in podzolic-B horizons. This was based on the premise that the extraction of organic matter by Na-pyrophosphate should contain the organically complexed iron and aluminum. It was commonly believed that it was in this form that iron and aluminum were deposited in the podzolic-B horizon.

Na-pyrophosphate extraction is done at pH 10 and, as is well known, sodium is an effective dispersing agent. This has caused and probably still is causing problems as it is very difficult to obtain clear supernatant solutions for analysis, usually by atomic absorption spectrophotometry. This may mean that in characterizing some soils the estimates of iron and aluminum may be too high. In fact, Loveland and Digby (1984) compared extraction of iron and aluminum from six replicate samples of seven soils and concluded that the results were so variable that comparison among them could not be made with confidence.

Citrate-dithionite-bicarbonate is another extraction solution that is used to extract iron and aluminum in soil. It is still required to characterize Bg horizons. The method was originally developed by Mehra and Jackson (1960) to "clean-up" clay materials for x-ray diffraction analyses. This extracting solution is also alkaline and sodium saturated. It may have the same problems as those associated with Na-pyrophosphate.

Acid ammonium oxalate (pH 3.0) has long been used as an extractant for sesquioxides and, later, silicon. In fact, the extractant was for some time used to characterize podzolic-B horizons in Canada. It is still used in many laboratories but now mainly to extract allophanes. There is currently much activity in this area in New Zealand, the United States, the United Kingdom, and in Canada - British Columbia.

Summary

Soil chemical analysis techniques have become more sophisticated as equipment has become more sophisticated. Soil taxonomies in their evolution continue to rely on soil chemical properties to differentiate taxa among soils. It is often stated that techniques are devised to aid pedologists in classifying soils into appropriate groupings. Others argue that the classification of soils has gone too far in terms of requiring chemical analysis before a soil can be classified, that the methods used become the criteria rather than soil morphology. There is no question in my mind that soil chemical analyses will continue to be important in soil taxonomy. Soil taxonomy is becoming more precise, class limits more sharply defined, and procedures specified. The problems that remain are standardization of procedures and methods, the recognition of soil variability, and better error analysis. Also, there has to be closer liaison between the field pedologist and the laboratory analyst. The field pedologist must be aware of limitations and advantages of methods used, the increased sophistication of equipment, and the analytical precision. The laboratory analyst must be aware of why criteria are needed, what precision or accuracy is required, and the problems associated with soil variability and soil sampling.

References

Fieldes, M. and Perrott, K.W. 1966. The nature of allophane in soils. Part 3. Rapid field and laboratory test for allophane. N. Zealand J. Sci. 9:623-629.

Loveland, P.J. and Digby, P. 1984. The extraction of Fe and Al by 0.1M pyrophosphate solutions: a comparison of some techniques. J. Soil Science 35:243-250.

Mehra, O.P. and Jackson, M.L. 1960. Iron oxide removal from soils and clays by a dithionite-citrate system buffered with sodium bicarbonate. Clays and Clay Minerals 5:317-327.

Schnitzer, M. and Wright, J.R. 1957. Extraction of organic matter from podzolic soils by means of dilute inorganic acids. Can. J. Soil Sci. 37:89-95.

Schuppli, P.A. and McKeague, J.A. 1984. Evaluation of some field tests for podzolic B horizons. Can. J. Soil Sci. 64:657-666.

Wada, K. and Harward, M.E. 1974. Amorphous clay constituents in soils. Adv. Agron. 26:211-260.

NINTH B.C. SOIL SCIENCE WORKSHOP

SESSION TWO - Approaches in Soil Analyses and Interpretations

February 21, 1985, P.M.

W. van Lierop, Session Chairman

Some Possible Approaches to Soil Nitrogen Availability Testing in Field Soils and Soil-less Mixes

by

Michael Rowell
Norwest Soil Research Inc. Langley, B.C.

INTRODUCTION

Nitrogen is invariably the critical element in crop production yet it is has a poor soil testing record.

A recent survey of soil testing laboratories in the United States showed that prediction of fertilizer needs are frequently based upon a combination of laboratory test results and a general "book value" approach involving yield potential and management information (Keeney, 1982). Table 1. shows the wide variety of chemical testing methods that have been used. A good test procedure should be capable of directly or indirectly assessing the potential of the soil to produce nitrogen in a form available to the plant. Such methods must be interpreted or calibrated using the results of field trials. In addition, the test should be rapid, inexpensive, reproducible and the results not significantly influenced by variations in sample handling or pretreatment.

Why does nitrogen create so many problems in soil testing ?

An overall view of the nitrogen cycle in soil shows how many problems arise (see Figure 1).

The interactions between the different components of the cycle are complex and involve numerous intermediate reactions and pathways. Many climatic variables, soil characteristics and agricultural practices affect plant yield and consequently the demand for nitrogen by the crop. The nitrogen cycle is a biological equilibrium between a large organic pool and a small inorganic pool. Gains and losses to the inorganic pool occur at several different points and each attains significance under a different set of soil conditions. Denitrification is favoured by high nitrate concentrations and warm water-saturated conditions. Atmospheric nitrogen fixation is high in legumes and other nodulated crops while asymbiotic fixation may also be significant under conditions of low oxygen tension and low ammonia concentrations. Also, volatilization of ammonia may be an important factor in soils of low absorption capacity at high pH.

Soils show different rates of conversion of organic nitrogen to ammonium and of ammonium to nitrate.

Accumulation of nitrate in humid climates may result in substantial leaching of nitrate to depths below the root absorbing zone.

In arid regions, especially where cropping periods are separated by a winter dormant period, the measurement of residual nitrate in the autumn or spring has proved to be an adequate soil test method. In some other areas laboratory testing for nitrogen has not been found suitable for fertilizer recommendations.

Fortunately a more utilitarian approach to testing was initiated by Stanford to define the mineralization potential or "nitrogen supplying power" of soils (Stanford et al. 1973, Stanford and Epstein, 1974). This work has been developed in subsequent years to the state that it may be of practical use in a testing program.

The formation of inorganic nitrogen under aerobic conditions conforms approximately to a first order kinetic reaction where:

$$Nt = No\ (1 - e^{-kt})$$

No = Potentially mineralizable-N (ug/g)
Nt = Net N mineralized in time t (ug/g)
t = Incubation time (weeks)
k = Rate constant

Relationships between the rate constant and net mineralization, and temperature and moisture seem to be mathematically rather simple. Hence a knowledge of No, and the velocity of mineralization as a function of temperature and moisture should allow a prediction of nitrogen release under field conditions. This approach has been followed by several researchers including a study by Campbell on the major zonal soils of the Canadian Prairies (Campbell et al., 1984).

Unfortunately it is normally found that the results of laboratory assessments correlate in an increasingly poorer fashion as comparisons are made with other laboratory methods, with greenhouse trials and with field trials. For instance, recent work by Fox and Piekielek (1984) for Corn in Pennsylvania showed good correlation between chemical and biological indeces such as anaerobically mineralized nitrogen, total soil nitrogen and boiling 0.01M calcium chloride extractable nitrogen. Correlation of these laboratory measurements with a calculation of plant uptake of nitrogen from soil sources, which included a discounting factor for starter nitrogen, were significantly poorer.

This paper presents some preliminary results from a study to investigate some possible soil test methods for nitrogen assessment in agricultural soils.

METHODS

A set of 53 soils were selected from farm soils analyzed in our laboratory during 1984. They were selected on the basis of organic matter content which varied from 1.0% to 71.2% . Soil pH varied from 3.74 to 8.08. Most soils were from the Lower Fraser Valley though some came form the more arid Interior and from Vancouver Island. The intended crops were largely corn and grass for silage or grass for pasture but several were for vegetable production.

A total of 9 tests were carried out which were hoped to be directly or indirectly related to nitrogen release. They were also chosen to be compatible with the requirements for testing methods as outlined earlier. Where long-term and short-term methods of a similar type existed, the short method was selected. The methods are outlined in Table 2.

A growth chamber experiment was carried out using barley as a test crop. Due to lack of available sample only 30 soils were included in this study.

RESULTS

The results of all tests except those involving total nitrogen are available at this time. All the laboratory methods studied were well correlated when analyzed by linear regression curve fitting methods. Residual mineral nitrogen correlated better than might have been expected but was inferior to comparisons between other direct methods such as calcium chloride autoclavable-N, aerobically mineralized-N and anaerobically mineralized-N.

Table 3. shows the range and mean for each measurement.

With the aerobic test, the results could be grouped depending on the mineralization pattern. Some 69% of the soils tended to accumulate ammonium far in excess of nitrate while 18% accumulated nitrate in comparison to ammonium. The remaining 13% produced ammonium and nitrate in roughly equivalent concentrations.

Table 4 shows the results of linear regression correlations between the different tests performed.

In the growth chamber experiment, above ground dry matter production was strongly correlated to the sum of the amount of mineral nitrogen present initially and that mineralized during the growth period. The latter was calculated from the results of the aerobic incubation test with allowance made for the temperature during the growing period. It might be anticipated that the correlation would be even higher when the results of nitrogen uptake rather than yield are used. A summary of these results is given in Table 5.

CONCLUSIONS

Only tentative conclusions may be drawn from the results so far.

Several direct laboratory measurements of potential mineralization may be useful in predicting nitrogen release in Lower Mainland soils. These seem more reliable than the customary measurement of residual ammonium and nitrate for such areas.

The results of aerobic incubations indicated that several different types of mineralization pattern exist. The relative rate of ammonification and nitrification reactions can result in accumulation of ammonium, accumulation of nitrate or accumulation of both ammonium and nitrate in varying amounts. If this can be related to soil type it would be useful information for suggesting the best type of nitrogen fertilizer to be applied in terms of possible denitrification and leaching losses, and plant uptake characteristics.

Despite the rather depressing conclusions from similar studies in the United States, the general approach seems to have merit in the context of British Columbia soils. It is apparent from the work carried out in Iowa and Pennsylvania that the "wide range" of soils that were studied is considerably less wide ranging than those cultivated in B.C. Stanford's soils showed a variation in carbon content of 0.5% to 3.0% while our soils varied between 0.5% and 40.0%. In Fox's study, anaerobically mineralized nitrogen varied between 25-87 ug-N/g (suggesting a rather narrow organic matter range) in comparison to 17-394 ug-N/g in our set of soils. Thus results from coastal B.C. soils may allow us to make broad groupings for recommendation purposes.

We would strongly suggest that continuation of research of the type outlined here is an important prerequisite to the production of a new nitrogen recommendation system for B.C.

Such a system would require input concerning:

1. Mineralization potentials of grouped B.C. soils to determine No and k values.
2. Temperature and moisture relationships related to the above soils.
3. Total uptake and time-course uptake for B.C. crops.
4. Measurement of the relationship of mineralization potential of soils with easily measured laboratory tests of nitrogen availablity potential.
5. Correlation of laboratory tests and mineralization potentials with field data.
6. Modification to recommendations based upon additional management practices, climatic variables and different target yields.

BIBLIOGRAPHY

Bremner, J.M. 1965a. Nitrogen Availability Indexes. In Methods of Soil Analysis, C.A. Black ed., American Society of Agronomy Inc., Madison Wisc., 1324-1345.

Bremner, J.M. 1965b. Total Nitrogen. In Methods of Soil Analysis, C.A. Black ed., American Society of Agronomy Inc., Madison Wisc., 1149-1178.

Campbell, C.A., Y.W. Jame and G.E. Winkleman 1984. Mineralization rate constants and their use for estimating nitrogen mineralization in some Canadian Prairie soils. Can. J. Soil Sci., 64: 333-343.

Fox R.H. and W.P. Piekielek 1984. Relationships among anaerobically mineralized nitrogen, chemical indexes, and nitrogen availability to corn. Soil Sci. Soc. Am. J. 48: 1087-1090.

Keeney D. R. 1982. Nitrogen-Availability Indeces. In Methods of Soil Analysis, Part 2, Agronomy Monograph No. 9 (2nd edit), American Society of Agronomy Inc., Madison Wisc., 711-733.

Keeney D. R. and J. M. Bremner 1967. Determination of isotope-ratio analysis of different forms of nitrogen in soils: VI. Mineralizable nitrogen. Soil Sci. Soc. Am. Proc., 31: 34-39.

Stanford, G., J.O. Legg and S.J. Smith 1973. Soil nitrogen availability evaluations based on nitrogen mineralization potentials of soils and uptake of labelled and unlabelled nitrogen in plants. Pl. Soil 39: 113-124.

Stanford G. and E. Epstein 1974. Mineralization-water relations in soils. Soil Sci. Soc. Am. Proc. 38: 103-107.

Stanford G. and S.J. Smith 1976. Estimating potentially mineralizable soil nitrogen from a chemical index of soil nitrogen availability. Soil Sci. 122: 71-76.

Table 1. Some Examples of Nitrogen Test Methods

Type	Description
1. Direct Biological	
Aerobic incubations	25-35 deg.C, 14-100 days ammonium + nitrate
Anaerobic incubations	30-40 deg.C, 7-21 days ammonium
2. Indirect Biological	
Soil respiration	carbon dioxide
Soil biomass	bacteria
3. Direct Chemical	
Residual mineral-N	ammonium + nitrate
Extraction with acids	ammonium
Extraction with bases	ammonium, total-N
Oxidization	ammonium
Water	total-N
Neutral salts	ammonium, total-N
(All the above carried	out hot & cold solutions)
Total nitrogen	Kjeldahl
4. Indirect Chemical	
Hot water extraction	organic-C
Barium hydroxide ext.	glucose
Potassium sulphate ext.	glucose
Oxidizing agents	carbon dioxide
calcium chloride or sodium bicarb. extr.	UV absorance
Organic matter	
Organic carbon	
Texture	

Table 2. Tests Carried Out To Assess Nitrogen Mineralization Potentials of Soils

Test Performed	Reference
1. Residual mineral nitrogen 2M KCl; ammonium + nitrate	Bremner, 1965a
2. Autoclavable nitrogen 0.01M calcium chloride;ammonium after 16 hrs, 121 deg.C	Stanford & Smith, 1976
3. Aerobically mineralized-N 35 deg.C, 14 days, 0.3 bar; ammonium + nitrate	Stanford & Epstein, 1974
4. Anaerobically mineralized-N 7 days, 40 deg.C, saturated; ammonium	Keeney & Bremner, 1967
5. Total nitrogen Kjeldahl; ammonium	Bremner, 1965b
6. Loss on ignition 420 deg.C, 4 hours, weight loss	
7. Organic carbon dry combustion, Leco furnace; carbon dioxide	
8. Carbon:Nitrogen Ratio from results of 5 & 7	
9. Bulk Density uniformly packed cyclinder of dried ground soil	

Allowance is made for residual mineral nitrogen in methods 2, 3 & 4.

Table 3. Results of Tests to Assess Nitrogen Mineralization Potentials using 53 Soils

Test Performed	Range	Mean
Residual Mineral-N ammonium + nitrate (ug/g)	3-131	32
Autoclavable-N ammonium (ug/g)	20-564	179
Aerobically Mineralized-N ammonium + nitrate (ug/g)	18-686	114
Anaerobically Mineralized-N ammonium (ug/g)	17-397	120
Loss on Ignition (%)	1.62-68.8	13.2
Organic Carbon (%)	0.55-40.0	6.51
Bulk Density (g/cm^3)	0.58-1.70	1.03

Results for autoclavable-N, aerobically & anaerobically mineralized-N are all corrected for residual mineral-N.

Aerobic mineralization:

Ammonium much greater than nitrate	69%
Nitrate much greater than ammonium	18%
Equivalent ammonium and nitrate	13%

Table 4. Examples of Linear Regression Using Test Results

X	Y	Regression Equation	R2
Aerobic-N	Anaerobic-N	Y = 49.7 + 0.62 X	0.70
Autoclavable-N	Anaerobic-N	Y = 19.3 + 0.56 X	0.81
Autoclavable-N	Aerobic-N	Y = 76.3 + 0.90 X	0.58
Aerobic-N	Residual Min-N	Y = 16.8 + 0.14 X	0.38
Organic-C	Autoclavable-N	Y = 78.1 + 15.4 X	0.77
Organic-C	Aerobic-N	Y = 27.5 + 13.3 X	0.79
Organic-C	Anaerobic-N	Y = 58.7 + 9.46 X	0.74
Organic-C	Loss on ignition	Y = 2.40 + 1.65 X	0.97
Organic-C	Residual Min-N	Y = 20.1 + 1.87 X	0.32
Bulk density	Organic-C	Y = 27.5 - 20.3 X	0.43

All the above are sigificant at the 5% level. The relationship between bulk density and organic carbon best fits a non-linear curve.

Table 5. Preliminary Yield Results for Growth Chamber Experiment using 30 soils

---

Yield Results:

Dry weight range	tops (mg/kg soil)	244-11060
	roots (mg/kg soil)	175- 5960
Dry weight mean	tops (mg/kg soil)	2350
	roots (mg/kg soil)	1870

Mineral Nitrogen Available:
Composed of residual mineral-N plus mineralized-N estimated from aerobic mineralization result.

range	(mg/kg soil)	40-1122
mean	(mg/kg soil)	202

Linear Regression:

X = Available nitrogen (mg/kg soil)

Y = Dry weight tops (mg/kg soil)

$Y = 663 + 8.34 X$ $r2 = 0.82$

Details :

30 Soils
Barley Test Crop
16 hour light period, 23 deg.C day, 15 deg.C night
Supplementary phosphorus and potassium given
No nitrogen
29 day growth period

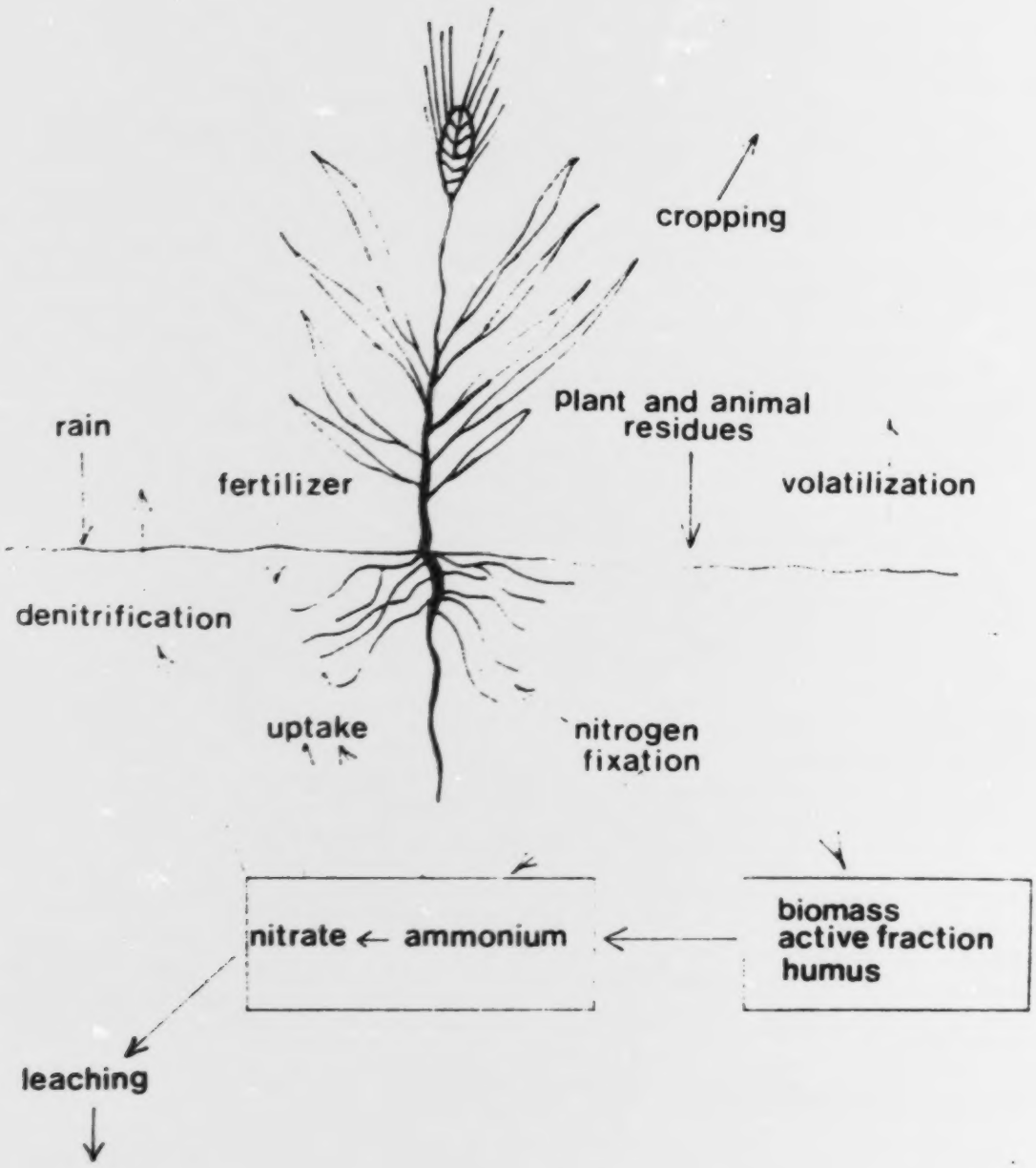


Figure 1. The Nitrogen Cycle for Soil and Crop Growth

BRAY'S SOIL TEST CALIBRATION THEORY

R.A. Bertrand[1], P.Ag.

NUTRIENT MOBILITY

Modern soil testing, for the purposes of assessing the fertility status of agricultural soils and determine fertilizer requirements, is based on the theories and research of Roger H. Bray at the University of Illinois. Bray's work is founded on the concept of "nutrient mobility" which holds that relatively immobile nutrients (P, K, Ca, Mg) are taken up by plants in proportion to the size of the root and root-hair system. Therefore, a given level of a plant nutrient in the soil will be equally adequate for a small yield during unfavourable growing seasons and for larger yields during more favourable seasons. The greater root volume produced by larger yields will contact and, therefore, take up, more nutrient than the smaller root volume resulting from lower yields.

Size of the plant does not correlate well with the adequacy of a relatively immobile nutrient for producing optimum yield. Much more important considerations are:

a) kind of plant
b) planting pattern and rate of planting
c) form of the nutrient
d) distribution of the nutrient in the soil in relation to planting pattern.

From these concepts, Bray developed soil tests for P and K. The requirements for a successful soil test were stated to be: proper extracting solutions, rapid and accurate measurement techniques, and correlation between lab measurements and crop growth.

EXTRACTING SOLUTIONS

Bray stated that the solution must extract the total amount of a plant available form of a nutrient or a proportionate part. Available forms were defined as "those whose variations in amount are responsible for significant variations in yield and response to applied fertilizers. An extractant that removes significant amounts of other, non available forms, or is effected by variations in other soil chemical factors (e.g. pH) is of no value for soil testing.

---

1. Director, Soils Branch, B.C. Ministry of Agriculture and Food, Surrey, B.C.

SPEED AND ACCURACY

A routine, producer oriented soil test program relies on both speed and accuracy. However, unsuitable extractants should never be used because of speed alone. Sacrifices in accuracy will greatly reduce the usefulness of the resulting fertilizer recommendations.

SOIL TEST CORRELATION

Correlation of laboratory soil test values with crop needs and response is the cornerstone of a quality soil test program. The field research program used by Bray involved comparing crop growth on a completely fertilized field plot to growth on a plot where the nutrient in question was deficient. The magnitude of the yield difference was the crop's measurement of the deficiency of that nutrient.

This relationship was expressed as the following equation which was developed by Mischerlich and Baule and modified by Bray:
$\text{Log } (A-y) = \log A - c_1 b_1$.

where: y is the yield without added fertilizer
A is the yield when the nutrient is adequate
b_1 is the soil test value of the unfertilized plot
c_1 is a proportionality constant.

The c_1 value is a constant for a particular crop at a given planting rate. After conducting a sufficient number of field experiments c_1 values can be established for various crops. Bray found that one value can be used for a fairly wide variety of soils and climatic conditions.

Additional field trials were used to determine the amount of fertilizer required to raise the yield on the deficient plot to that on the adequately fertilized plot. The data obtained was analyzed using the following equation:

$\text{Log } (A-y) = \log A - (c_1 b_1 + cx)$
where: x is the rate of fertilizer applied
c is a proportionality constant.

When both c_1 and c have been adequately defined, through field research, soil testing can be used to answer practical producer questions concerning soil fertility and fertilization.

B.C. SITUATION

The soil testing service conducted by BCMAF is based on Bray's theories and research findings. The fertilizer recommendations based on Bray's work have often been questioned and many soil

test labs have adopted other methods for arriving at recommendations. Most of the other methods result in higher fertilizer use. Users of the Bray system have been critized for being conservative and penalizing the leading progressive farmers in favour of the average farmer.

A project was conducted at the University of Nebraska by Olson and colleagues to compare fertilizer recommendations from the University lab (using Bray's theories) with four private labs. Corn was grown for 8 to 9 years and fertilizer applied according to the soil tests conducted by 5 different labs. Yields were not significantly different over the test period. However, total fertilizer costs for the test period were much different. The private lab recommendations resulted in from \$60/ac to \$380/ac more fertilizer being used than if the University recommendations were followed.

FUTURE WORK

Bray's theories of soil testing have been widely tested and are widely accepted. However, in B.C. the amount of local research that has gone into developing the c_1 and c values is minimal. Considerable work is required to modify these values for: other regions, more crops, new planting and fertilizer techniques, and for more nutrients than P and K.

LIST OF REFERENCES

Bates, T.E. 1970. Factors affecting critical nutrient concentrations in plants and their evaluation: a review. J. Soil Sci. 112: 116-130.

Black, C.A. 1955. Evaluation of nutrient availability in soils, and prediction of yield response to fertilization. Iowa St. Coll. J. Sci. 6: 1-11.

Bray, R.H. 1944. Soil-plant relations: I. The quantitative relation of exchangeable potassium to crop yields and to crop response to potash additions. J. Soil Sci. 58: 305-324.

Bray, R.H. 1945. Soil-plant relations: II. Balanced fertilizer use through soil tests for potassium and phosphorus. J. Soil Sci. 463-473.

Bray, R.H. 1948. Requirements for successful soil tests. J. Soil Sci. 66: 83-89.

Bray, R.H. 1962. Confirmation of the nutrient mobility concept of soil-plant relationships. J. Soil Sci. 95: 124-130.

Cook, F.D., F.G. Warder, and J.L. Doughty. 1956. Relationship of nitrate accumulation to yield response of wheat in some Saskatchewan soils. Can. J. Soil Sci. 37: 84-88.

Olson, R.A., K.D. Frank, P.A. Grabouski, and G.W. Rehm. 1982. Soil Testing philosophies, consequences of varying recommendations. Crops and Soils Magazine, pp. 15-18, Oct. 1982.

Laboratory Determination and Interpretation of Soil Physical Properties

Michael J. Goldstein P.Ag.[1]

Abstract

The role of routine laboratory soil physical property analysis in resource management is discussed. The standard methods of analysis of routine laboratory soil physical tests are reviewed, including: particle size anaysis, bulk density, soil water retention, soil compaction, and modulus of rupture. Types of interpretations, which can be made from these tests are suggested. It is concluded that routine laboratory analysis of physical properties can make an important contribution to resource management.

Introduction

This talk is intended to be a general introduction to the field of laboratory analysis of soil physical properties. Two questions are posed.

1. Can soil physical properties be as efficiently measured as chemical properties ?
2. Can soil physical properties determined in the lab be used to make day to day resource management decisions ?

I will also share a few pointers I've learned in five years of offering routine soil physical property analyses to the public.

President, Soilcon Laboratories Ltd.

Particle Size Analysis

Particle size analysis is the most often requested physical property analysis. A later speaker will discuss methods for determining the size distribution of fine particles. Many B.C. soils are very stoney and their management often also requires a knowledge of the size distribution of soil particles over 2mm in diameter. Sieve testing is the routine method used to accomplish this. The Ro-Tap sieve shaker is the standard; however, less expensive shakers can be used. A stack of sieves is used such that the mesh opening of a sieve is about half that of the one above. This prevents the mesh becoming clogged. A common error is to sieve too large a sample a once. A sample splitter is a rapid way to reduce the sample to a size where no more than 100 g is left on any sieve.

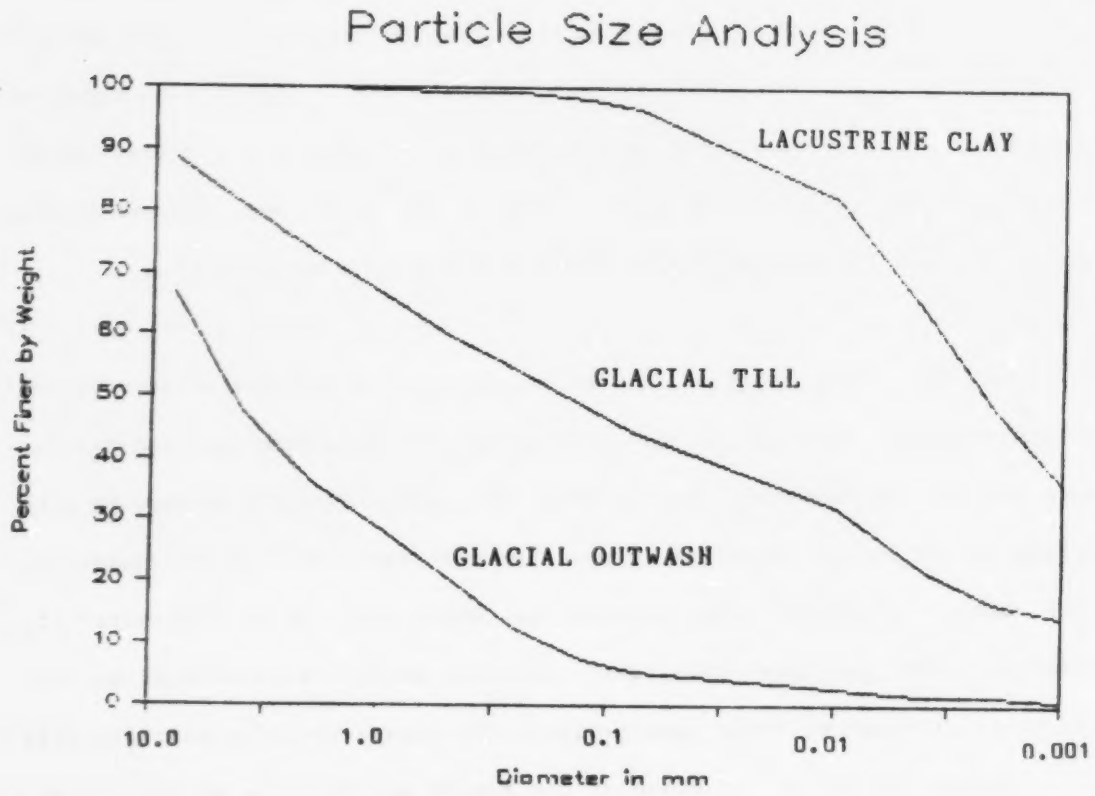
The major use of particle size anaysis is in determining the method of deposition of parent materials. Figure 1 shows how several parent materials vary in their particle size distribution characteristics.

Particle size distribution is used to make a wide variety of engineering interpretations including: soil limitations for septic absorption fields, excavations, embankments, foundations, and roads. It is also used to make estimates of other physical properties such as: hydraulic conductivity, soil water retention, and compaction. While these properties correlate somewhat with particle size distribution, other factors such as soil structure influence these properties. The errors in using particle size distribution estimates in place of the proper analyses can be very large.

Many of these other physical properties can be determined directly in the laboratory, at less expenses than particle size. Be careful not to over-use particle size distribution to make resouce management decisions.

Often particle size distribution is determined in the field by the "hand feel" method. Even seasoned pedologists make large errors between the silt and clay fractions by the hand feel method. Normally laboratory testing of every tenth sample is needed to keep hand texturing on track.

Figure 1 Particle Size Distribution Curves of Various Parent Materials.



Bulk Density

Particle size distribution has one very important shortcoming. It is performed on a disturbed sample. No information on the field condition of the sample can be obtained from particle size analysis. Bulk density is the simplest and most common method of measuring field condition. Bulk Density is the dry mass of soil per unit volume.

Core sampling is the most common method of determining bulk density. Core samplers can only be used on soils where the size of the largest common stones is less than 20% of the cores diameter. The alternatives to core sampling are excavation and gamma ray attenuation. The soil in the cores can be compacted when the core is pounded into the soil. To minimize this, cores and samplers should be as thin walled as possible, as short as possible and have as large a diameter as possible.

Bulk density is used to convert mass based measurements, such as soil nutrient concentration, to a volume or area basis; for example, ppm to Kg/ha. Often our chemical knowledge of a soil is dependent on our physical knowledge of the soil. Bulk density is also used in conjunction with soil compaction tests. Table 1 includes soil water retention and bulk density data obtained using 2 inch diameter core samples on a forest soil. These bulk densities are used to convert the volumetric soil water retention information to gravimetric ($ml H_2O/ml$ soil to $gm H_2O/gm$ dry soil), for comparison to gravimetric water samples.

Table 1 Bulk Density and Soil Water Retention Data for a B.C. Forest Soil

SAMPLE	Volumetric Soil Content (%) at -10J/kg	-33J/kg	-100J/kg	-300J/kg	-1500J/kg	Bulk Density kg/m3
sample 1	18.33	15.68	14.03	12.48	9.94	1224.78
sample 2	20.61	17.64	15.48	14.15	11.47	1257.35
sample 3	16.71	11.99	9.05	6.05	1.07	1396.54
sample 4	23.17	18.07	15.50	13.46	11.27	1116.43
sample 5	16.05	14.27	12.65	10.78	7.72	1412.97
AVERAGE	18.97	15.53	13.34	11.38	8.29	1281.61
STAN. DEV.	2.62	2.24	2.39	2.90	3.85	110.97
Coeff. of Var.	13.81%	14.42%	17.93%	25.45%	46.45%	8.66%

Variability

Table 1 also demonstrates the problem of variability. The five samples were taken of a single soil horizon type throughout a variable forest unit. Notice that the coefficient of variation for bulk denity is only 8.6%. This compares favorably with the variablity of chemical properties on such a site. Forest soils, especially surface horizons, are very variable. The level of variablility itself is a measureable physical property, and can be effectively employed as a resource management tool. Notice the variability of the soil water retention data. A highly variable soil may have more seedling planting opportunities than a soil with the same average values but lower variability. For routine operational work 5 to 9 samples per horizon is usually sufficient to characterize a physical property of a management unit.

Soil Water Retention

Soil water potential is the amount of energy required to move water from soil to a reference state. In most operational work, soil matric potential, commonly referred to as soil moisture tension, is the component of interest. In most soils a tension value of 10 to 33 J/kg is considered to be the field capacity of soil, (the matric force required to prevent significant amount of water from draining). A tension value of 1500 J/kg is thought to be the point where many agricultural crops suffer physiological damage. Many commercial tree species can avoid physiological damage, but little growth is achieved at tensions dryer than 300 J/kg.

Figure 2 shows a soil water retention curve based on the averages given in table 1. The routine laboratory procedure for soil water retention tests uses a pressure chamber or Richardson apparatus. Samples are subjected to a pressure which forces water out of the soil until the the matric potential is equal to the pressure potential. The samples are then removed and their water content measured. If the samples used are core samples than the volumetric water retention curve can be obtained.

Water retention characteristics are an important input into many models that predict crop and tree growth. Figure 4 shows the results of a water balance model which can either use measured soil water retention characteristics or water retention characteristics estimated from particle size data. Models of this type have the potential of becoming very important tools in resource management, as they allow the results of alternatve practices to be predicted.

Figure 2 Graph of Soil Water Retention Data in Table 1

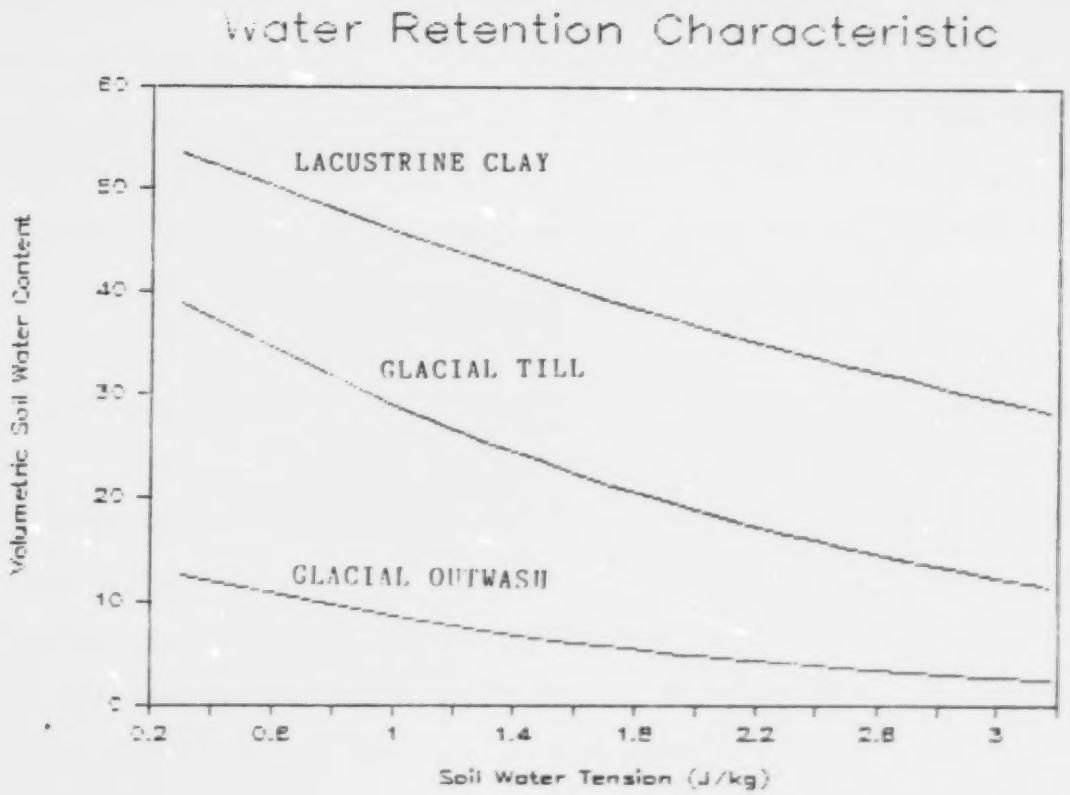
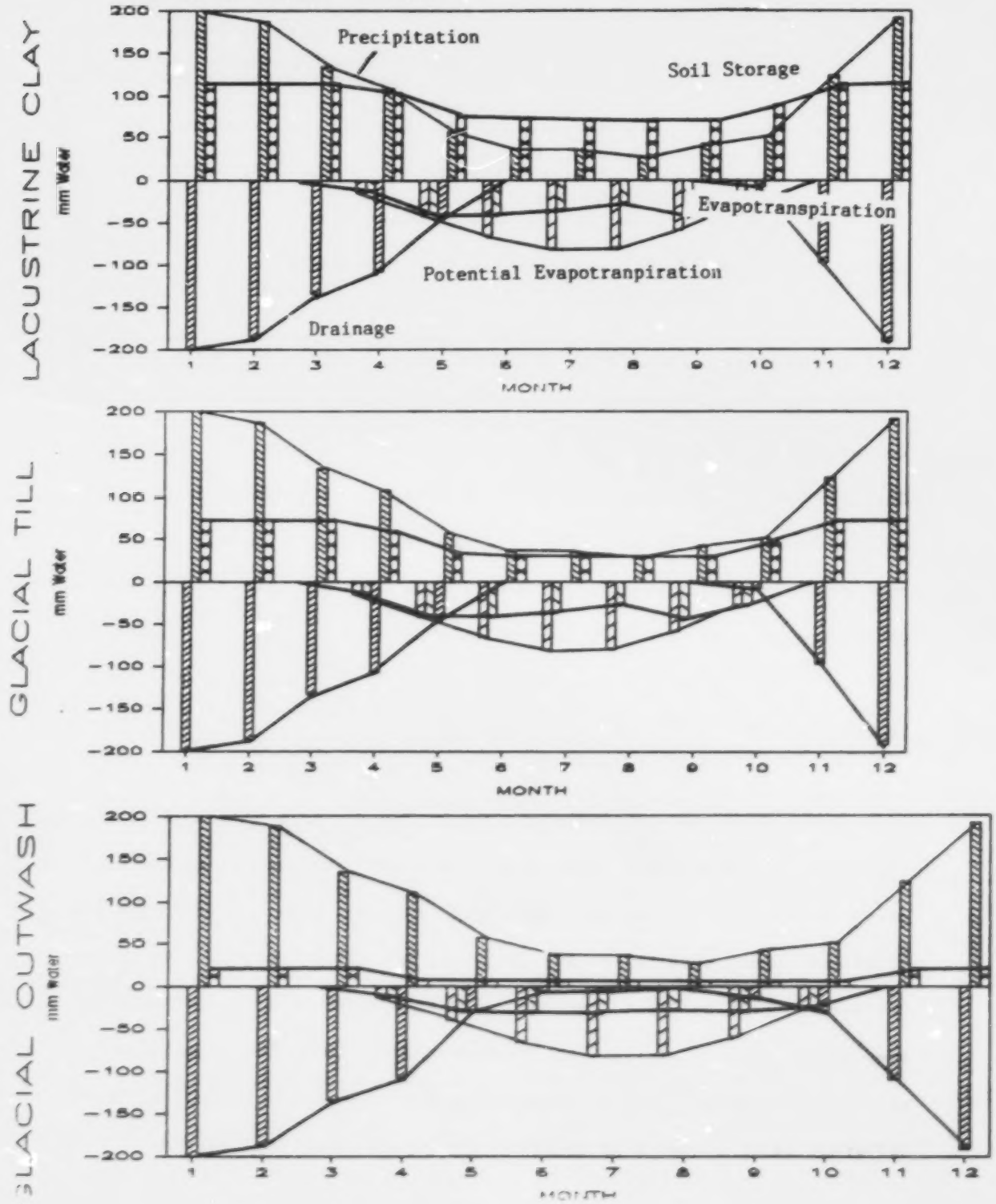


Figure 3 Water Balances Predicted by a Computer Model Using Retention Data for the Soils Used in Figure 1



Hydraulic Conductivity

Hydraulic conductivity is a measure of how fast water will travel through soil. Hydraulic conductivity can be measured in the laboratory using disturbed samples, 'undisturbed' core samples, or samples which have undergone compaction. Either a static or falling head method can be used. The type and magnitude of hydraulic head used in the laboratory test should be similar to that which exists in the field.

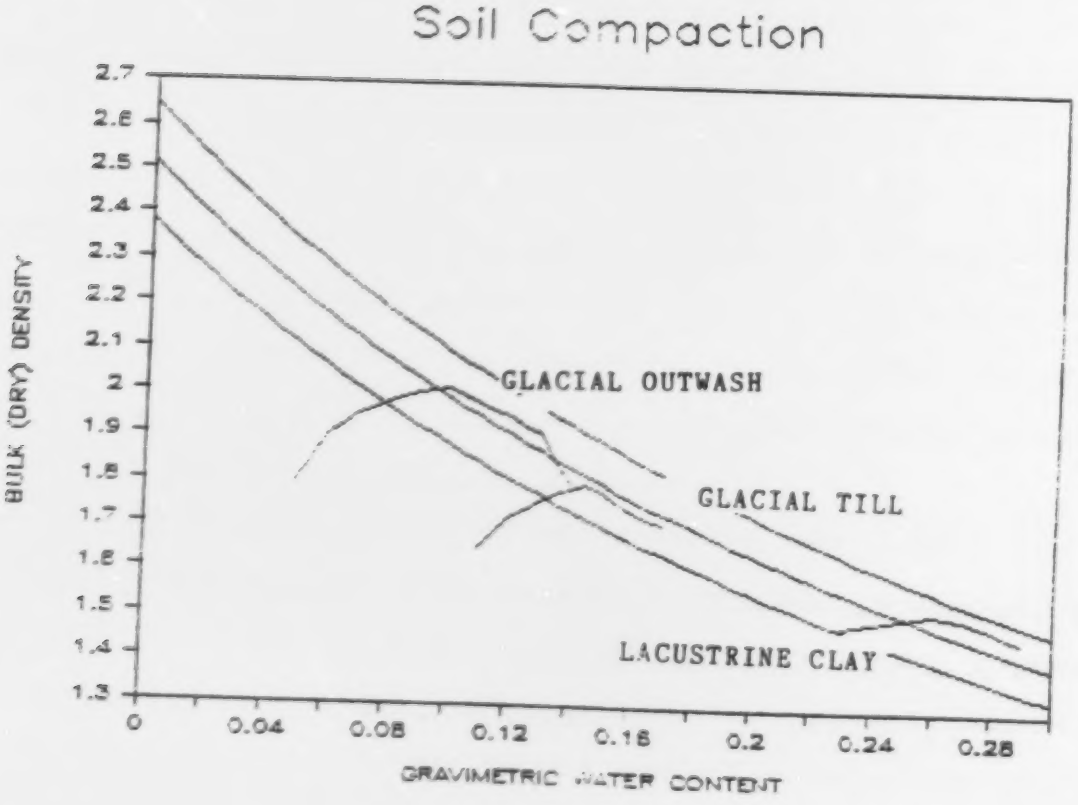
Most commonly, hydraulic conductivity is measured under saturated conditions. When a soil becomes unsaturated its hydraulic conductivity decreases by orders of magnitude. Unsaturated conductivity is mesured at Soilcon using a differential vacuum apparatus. Unsaturated conductivities in the range 20 to 60 J/kg can be efficiently measured with this apparatus. Water retention information is then used to estimate the rest of the unsaturated hydraulic conductivity curve.

Soil Compaction

Soil compaction is the increase in bulk density of a soil which has been subjected to mechanical pressure. The amount a soil will compact with a given compactive effort is dependent on the type of soil, the field condition (bulk density) of the soil, and its water content. The standard Proctor Compaction test can be used to predict this relationship for a compactive effort similar to that caused by rubber tired vehicles. The soil is compacted in a standard mold, with a standard hammer, at several different water contents to generate the curves shown in figure 4.

The highest point on the curve is the "Proctor" or optimum compaction. Road construction contracts often call for achieving 85 % of optimum compaction. A compaction test can be used to avoid compaction as well as achieve it. If forest landing sites were tested for compaction they could be divided into groups based on their susceptibility to compaction. Alternative sites or logging practices could be chosen in sensitive areas, or logging could be limited to periods when the soil is dry or frozen.

Figure 4 Proctor Compaction Cures for Sample Soils.



Once a soil is compacted in the lab, many other physical property tests can be run on it. Soil water retention curves would show how compaction has affected the pore size distribution of the soil. If a soil is compacted when over 95 percent of the voids are occupied by water, the soil "remolds" without an increase in bulk density. The macro-porosity of a remolded soil is greatly reduced. Such a soil acts compacted; ie, its hydraulic conductivity may have fallen by an order of magnitude and aeration may be greatly restricted even without a measurable change in bulk density.

Modulus of Rupture

Modulus of Rupture is a measure of the breaking strength of surface soil crusts. Soil crusts form when bare soil containing either salts or clay is exposed to weathering. These crusts can lead to the failure of such practices as hydro-seeding. As with many soil physical property tests, standardization of equipment and procedures is important to the interpretive power of this test. Standards for modulus of rupture tests are set by the U.S. Dept. of Agriculture and the American Society for Testing Materials (ASTM).

Table 2 shows some modulus of rupture results obtained on B.C. forest soils. Values under 2,000 millibars are good; those over 5,000 millibars indicate crust formation could seriouly inhibit regeneration. Note the variability of the test results. While Modulus of Rupture tests are rarely used in British Columbia, they are standard practice in Alberta for mine reclaimation.

Table 2 Results of Modulus of Rupture Tests

Modulus of Rupture millibars	Standard deviation of 5 replications	Coefficient of Variation
6253	856	13.6%
4808	453	9.4%
1572	206	13.1%
9913	1311	13.2%
864	107	12.4%
3845	851	22.1%

Conclusions

At the start two question were posed.

1. Can soil physical properties be as efficienty measured as chemical properties ?

2. Can soil physical properties, determined in the lab be used to make day to day resource management decisions ?

To the first question I would answer an unequivical yes. Soil physical properties can and are being measured routinely with similar accuracies and costs as routine chemical analyses.

To the second question I would answer yes add this comment. The contributions chemical analyses make to agriculture and forestry is considerable, and it is at least possible to estimate its portential for further contributions. The contribution of soil physical analyses to resource management at the present time is unknown. In the future the contribution of soil physical analysis could mean the difference between resoure management and watching our resources erode away.

Soil Variability with Respect to Soil Test Values

by A. L. van Ryswyk, John W. Hall, and W. van Lierop

Agriculture Canada, Kamloops and Vancouver, and
B. C. Ministry of Agriculture and Food, Kelowna

Abstract

An area (80 x 100m), situated on river alluvium near Kamloops and cultivated for more than 50 years, was sampled in August 1984, at the intersect points of a 10 m grid by obtaining 4 soil cores (2 cm diam. 0 to 15 cm depth) spaced 0.4 m apart immediately east of each point. Each core was analyzed by the Soil, Feed and Tissue Testing Laboratory, B.C.M.A. & F., Kelowna for the plant available nutrients - NO_3, P, K, Ca, and Mg. Examination of the semi-variances indicated that the maximum east-west variability was reached at about 10 m for NO_3, 3 m for P, 10 m for K, one m for Ca and 30 m for Mg; comparable distances for north-south variability were 80, 100+, 100+, 70, 20.

This study gives information useful in designing sampling schemes for a variety of fertilization strategies that producers may chose. In particular, it has indicated that fertility, as measured by the analysed factors, may be thought of as a response surface. Depending on fertilization strategy adopted, the goal of soil sampling may be either to determine an average value for the surface or to determine the form of the surface itself. Samples from this site may be considered independent of each other as long as they are 10 to 20 m or more apart. As the distance between them decreases, within this range, they become more correlated. Nevertheless, even at distances of one meter there is still considerable varibility between samples. Further study, including preparation of a detailed soil map, is planned to determine the usefulness of this data in developing soil sampling goals for fertilization strategies.

A COMPARISON OF AVAILABLE ZINC EXTRACTANTS FOR SOUTHERN INTERIOR ORCHARD SOILS

D. Neilsen[1], P.B. Hoyt[2]
and A.F. Mackenzie[1]

SUMMARY

Widespread Zn deficiency in Okanagan orchards has been reported (Woodbridge 1954) and in response, foliar application of Zn fertilizer is common practice. Twenty soils, characteristic of Southern Interior Orchard soils, were assessed for Zn availability using; a) a test crop of navy beans (Phaseolus vulgaris 'White marrow') in a greenhouse experiment and b) four chemical extractants; M $MgCl_2$, DTPA, 0.1M HCl + 0.1M H_2SO_4 (double acid).

In the greenhouse experiment, two treatments, 0-Zn and 10 ppm Zn were replicated 3 times in a split plot arrangement in a randomised complete block design. No significant increase in dry matter production occurred in response to added Zn although significant increases in plant Zn concentration occurred for most soils. Plant Zn uptake (plant Zn concentration X dry wt) from untreated soils varied from 33 to 865 ug per pot and indicated that a wide range of available Zn existed for these soils. Similar variability occurred for Zn extracted by all four chemical extractants. On average, 0.1M HCl extracted the largest amounts of Zn (6.8 to 161.8 mg. kg^{-1}) and M $MgCl_2$ extracted the smallest amounts of Zn (0.4 to 34.2 mg. kg^{-1}).

The wide range of available Zn exhibited by both plant uptake and chemical extractants may be attributable to several causes. For example total Zn, for these soils, varied from 51.5 to 226.3 mg. kg^{-1} and was significantly positively correlated with plant Zn uptake ($r=0.60$, $p<0.01$) and Zn extracted by M $MgCl_2$ ($r=0.64$, $p<0.01$), DTPA ($r=0.88$, $p<0.01$), 0.1M HCl ($r=0.88$, $p<0.01$) and double acid ($r=0.85$, $p<0.01$). Three indices of availability, plant Zn concentration, plant Zn uptake and M $MgCl_2$ extractable Zn were significantly negatively correlated with pH ($r=-0.61$, $p<0.01$; $r=-0.56$, $p<0.05$; $r=-0.56$, $p<0.05$, respectively). This suggests that the effects of recently reported fertilizer induced acidification of orchard soils in the S. Interior (Ross et al, 1985) could include increased Zn availability.

Amounts of Zn extracted from soils by all four procedures were highly significantly correlated with each other, although a much stronger relationship occurred between DTPA, 0.1M HCl and double acid ($r=0.98$ to 0.99, $p<0.01$) extractions than between these three and the M $MgCl_2$ extraction.

Available Zn measured by all four extractants was positively correlated with Zn concentration and uptake in the plant. For both plant Zn concentration and uptake, the strongest correlation occurred with M $MgCl_2$ ($r=0.69$, $p<0.01$ and $r=0.94$, $p<0.01$, respectively).

[1]Macdonald College, McGill University, Ste. Anne de Bellevue, Que. (Work in preparation for Ph.D. thesis).

[2]Agriculture Canada, Summerland, B.C.

Analytical problems encountered in aspirating M $MgCl_2$ solutions during atomic absorption spectrophotometry were overcome by the use of a more dilute solution, 0.25M $MgCl_2$. Zn extracted by 0.25M $MgCl_2$ was more closely related to plant Zn concentration ($r=0.80$, $p<0.01$) than the four initial extractants (M $MgCl_2$, DTPA, 0.1M HCl and double acid) and was also significantly correlated with plant Zn uptake ($r=0.94$, $p<0.01$).

0.25M $MgCl_2$ soil-extractable Zn shows promise as a measure of available Zn. Work is currently in progress to elucidate the fraction of soil Zn extracted by 0.25M $MgCl_2$ and to establish the relationship between this extraction and apple leaf Zn levels in forty commercial orchards.

Literature cited:

Ross, G.J., Hoyt, P.B. and Neilsen, G.H. 1985. Soil chemical and mineralogical changes due to acidification in Okanagan apple orchards. Can J. Soil Sci. (in press).

Woodbridge, C.G. 1954. Zinc deficiency in fruit trees in the Okanagan Valley in British Columbai. Can J. Agric. Sci. 34: 545-551.

COMPARISON OF THE PIPETTE AND HYDROMETER METHODS FOR DETERMINING SOIL PARTICLE-SIZE DISTRIBUTION.

Hong Chuah and W. van Lierop
British Columbia Ministry of Agriculture and Food, Kelowna, B.C. V1Y 4R2

The objectives of this study were to compare the relative efficacy and analytical processing rate of some hydrometric procedures relative to the pipette method for establishing particle-size distribution and textural classification of a wide range of soils. The pipette procedure was utilized as suggested by the CSSC after removal of soil organic matter by peroxidation with H_2O_2. The relative rate of soil organic matter oxidation by NaOCl (pH 9.5) and its effect on particle-size distribution was also determined using the pipette procedure.

Two hydrometric procedures were verified to determine the proportion of soil particles that were greater than 50 microns (sand) and smaller than 2 microns (clay) in size. The tested procedures differed principally in the sedimentation interval utilized to measure soil particle fractions. The first method is called the hydrometer method (Day, 1965), and the second the Bouyoucos method (Bouyoucos, 1962). However, both of these methods relied on the 152H ASTM hydrometer calibrated in grams of suspended soil particles per liter. Readings taken at the 30 second and 1 minute, and 4½ and 18 hour intervals were used to determine the sand and clay fractions, respectively, for the hydrometer method. The readings were plotted on a semi-logarithmic scale (logarithmic x-axis) against the percentage suspended soil particles (Y-axis). The actual percentage of soil particles left in suspension smaller than 50 (silt and clay) and 2 microns (clay) were determined by interpolation. Therefore, actual sand and silt fractions were obtained by difference. Readings for the Bouyoucos method were obtained at different sedimentation intervals: percentage sand (100-% silt and clay) and clay readings were taken 40-seconds and 2-hours after suspending soil particles, respectively. The effect of organic matter on particle-size distribution determination was also verified. Accordingly, readings were compared on soil samples which had the organic matter present and removed by peroxidation with H_2O_2 using both methods.

The hydrometer procedures were evaluated by comparing analytical values with those obtained by the pipette procedure using linear regression and correlation techniques. Twenty soils ranging in sand from 0.1 to 80, in silt from 15 to 80, and clay from 7 to 73% were used to compare the tested procedures. The pH, organic matter (Walkley-Black), and conductivity levels of the soils utilized in this study ranged from pH 3.8 to 8.2 (H_2O), O.M. 0.2 to 17%, and 0.2 to 14.2 dS/m, respectively. Salts were removed from soil samples which had the organic matter removed; this was achieved by washing samples from 5 to 7 times by means of decantations and a filter candle. Salts were also removed from soil samples which had a conductivity greater than 2 dS/m (1:1 soil-water ratio). All soil samples were dispersed before analysis by shaking overnight in a deflocculating agent consisting of 3.57g sodium hexametaphosphate and 0.794g sodium carbonate per 50g soil.

Removal of soil organic matter with NaOCl did not appreciably affect the sand, silt, and clay fractions. This fact was revealed by the practically 1:1 slopes obtained when comparing data from corresponding samples from which the organic matter had been removed by either NaOCl or H_2O_2. Furthermore, if the rate of organic matter oxidation by NaOCl was different from H_2O_2, it was not sufficiently so to significantly increase the rate of particle-size analysis to favor one agent over the other when using the pipette procedure. However, a small saving in reagent cost might be obtained by using NaOCl, which is commerically available, compared to H_2O_2.

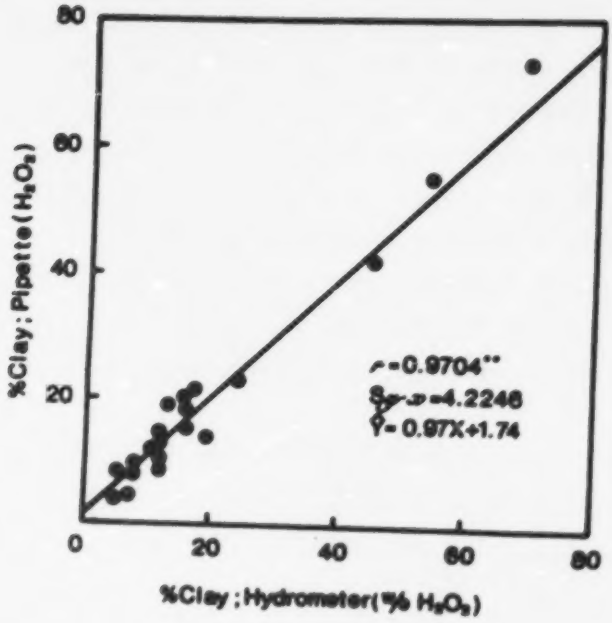
Regression and correlation values obtained by comparing particles fractions in corresponding soil samples after removing organic matter with NaOCl (X) and H_2O_2 (Y) with the pipette method.

Fraction	$\bar{Y}$	$\bar{X}$	Equation	r-value	$s_{y.x}$
sand (>50μ)	29.8	31.1	$\hat{Y}$= 1.03X-2.2	0.988**	4.1
silt (<50μ>2μ)	50.8	50.7	$\hat{Y}$= 0.997X+0.32	0.997**	4.8
clay (<2μ)	18.5	16.5	$\hat{Y}$= 0.974X+2.5	0.994**	2.3

Particle-size analysis values of soils obtained by means of the hydrometer procedures were closely correlated with those obtained with the pipette method. Results indicate that organic matter removal is not required for performing an accurate particle-size analysis. This conclusion is based on the observations that practically identical regression and correlation values were obtained for the relationship between the hydrometer and pipette methods whether the organic matter was present or removed when using the hydrometer. Furthermore, comparing the analytical values obtained by the hydrometer on soils with and without organic matter by means of regression and correlation techniques confirmed that the presence or absence of organic matter does not significantly influence particle-size analysis values with the soils of this study. Consequently, removing the organic matter did not affect the textural classification of the soils of this study. Apparently, removing soil organic matter only increased the proportions of silt-size particles slightly at the expense of the sand fractions.

Regression equations and correlation values obtained by comparing soil particle analysis data by means of the hydrometer and pipette procedures.

Comparison	Fractions	$\bar{X}$	$\bar{Y}$	Equations	r-value	sy.x
Pipette (H_2O_2;Y)	sand	28.6	28.5	$\hat{Y}$=0.93X-1.9	0.98**	4.4
vs.	silt	51.7	52.0	$\hat{Y}$=0.87X+6.9	0.96**	6.0
Hydrometer (H_2O_2;x)	clay	20.2	19.7	$\hat{Y}$=0.97X+1.1	0.98**	3.1
Pipette (H_2O_2;Y)	sand	27.2	28.5	$\hat{Y}$=0.95X+2.7	0.98**	5.2
vs.	silt	53.7	52.0	$\hat{Y}$=0.81X+8.3	0.97**	5.3
Hydrometer (O.M.;x)	clay	19.7	20.2	$\hat{Y}$=0.97X+1.7	0.97**	4.2
Hydrometer (H_2O_2;Y)	sand	27.2	28.6	$\hat{Y}$=X+1.2	0.98**	5.0
vs.	silt	53.7	51.7	$\hat{Y}$=0.91X+2.7	0.98**	3.9
Hydrometer (O.M.;x)	clay	19.1	19.7	$\hat{Y}$=X+0.6	0.99**	2.7



Relationships between the clay values obtained with the hydrometer and pipette procedures for the range of values encountered with the soils of this study. Soil samples analyzed with the hydrometer contained organic matter while those analyzed with the pipette had the organic matter removed.

COMPARISON OF SOIL TEXTURAL CLASSIFICATION AS RELATED TO METHODS

METHODS	SOILS #											
	1	2	3,6,13,16	4,5	7,8,9	10,11,15	12	14	17	18	19	20
Pipette, H_2O_2	Sil	Sil	Sil	SL	Sil	SL	Sic	Sic	L	L	L	LS
Pipette, NaOCl	✓	✓	✓	✓	-✓	✓	✓	✓	✓	✓	✓	✓
Hydrometer, H_2O_2	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Hydrometer, $^{w}/_{o}$ H_2O_2	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Bouyoucos, H_2O_2	✓	SiCL	✓	✓	SiCL	✓	c	✓	✓	✓	✓	SL
Bouyoucos, $^{w}/_{o}$ H_2O_2	L	-	-- ✓✓	L	-	✓	c	✓	✓	✓	CL	SL

- not determined

Comparison of soil particle fractions measured with the Bouyoucos and the pipette procedure on samples with and without organic matter indicated that clay, silt, and sand values were closely related. However, the average clay and silt levels measured by the Bouyoucos method were 135 and 83% of those found with the pipette procedure. These differences are probably related to the much shorter sedimentation interval used for the Bouyoucos compared to the pipette method which implies that the former includes a significant proportion of the finer silt particles along with the clay determination. The differences observed between the Bouyoucos and the pipette procedure are often large enough to provide a different textural classification. As with the hydrometer procedure, removal of soil organic matter did not appear to affect soil sand, silt, or clay values obtained with the Bouyoucos procedure.

Regression equations and correlation values obtained by comparing soil particle fractions by means of the pipette and Bouyoucos procedures.

Comparison	Fractions	$\bar{X}$	$\bar{Y}$	Equations	r-value	Sy.x
Pipette (H_2O_2;Y) vs. Bouyoucos (H_2O_2;X)	sand	28.4	28.6	Y=0.95X+1.4	0.98**	4.7
	silt	42.8	51.6	Y=0.93X+11.8	0.944**	7.1
	clay	28.8	20.6	Y=0.82X-3	0.956**	5.3
Pipette (H_2O_2;Y) vs. Bouyoucos (O.M.;X)	sand	37.2	35.7	Y=1.05X-3.4	0.956**	8.3
	silt	34.2	42.1	Y=0.98X+8.4	0.92**	7.2
	clay	28.6	21.5	Y=0.96X-6	0.978**	4.7
Bouyoucos (H_2O_2;Y) vs. Bouyoucos (O.M.;X)	sand	38.0	39.0	Y=1.01X+0.5	0.993**	3.3
	silt	33.1	32.6	Y=1.03X-1.2	0.988**	2.8
	clay	30.2	28.3	Y=1.03X-1.9	0.996**	2.1

CONCLUSIONS

Removing soil organic matter from samples as part of the particle-size analysis procedure increased the time required to complete analyses by about fourfold. Substituting NaOCl for H_2O_2 did not materially improve the organic matter oxidation rate or affect soil textural classification.

Comparisons of data obtained by the hydrometer and Bouyoucos procedures revealed that particle-size fractions obtained by either of these procedures were not significantly different whether soil samples contained or had the organic matter removed. Accordingly, a four or fivefold increase in the rate of analyses can be achieved by using either the hydrometer or Bouyoucos procedure.

The clay and silt values obtained with the Bouyoucos procedure were significantly higher and lower than those obtained by the pipette procedure, respectively. These differences were ascribed to the inclusion of some of the finer silt with the clay at the expense of lower silt readings. Apparently, the shorter 2-hour sedimentation interval utilized to determine the clay fraction was responsible for the higher clay values. Unfortunately, the differences in particle-size fractions obtained by the Bouyoucos procedure resulted in classifying from 20-40% of the soils in a different textural group than the pipette procedure. However the 40-second reading (silt and clay) utilized to determine the sand fraction provided practically similar values ($r=0.98^{**}$; $Y=X+0.76$; $sy.x=5$) for sand than the double reading utilized with the hydrometer procedure.

Particle-size analysis values obtained by using the hydrometer method on soil samples containing organic matter were closely related to values observed with the pipette procedure over the range of soils studied. Furthermore, the soils used to verify the hydrometer procedure were classified in the same textural division as those analyzed with the pipette method. For these reasons plus the fact that a four to fivefold increase in sample processing rate was achieved by substituting the hydrometer for the pipette procedure, our laboratory has adopted the hydrometer procedure with soils containing less than 20% organic matter for routine particle-size analysis.

FACTORS AFFECTING LEAF ZN CONCENTRATION OF 'MCINTOSH' SEEDLINGS GROWN IN NUTRIENT SOLUTION

G.H. NEILSEN and E.J. HOGUE[1]
AGRICULTURE CANADA, RESEARCH STATION SUMMERLAND, B.C., CANADA V0H 1Z0

ADDITIONAL INDEX WORDS. Zn deficiency, leaf P/Zn, P toxicity

ABSTRACT. Mid terminal leaf Zn concentration of apple seedlings (Malus domestica Borkh. cv. McIntosh), grown in greenhouse experiments for 4-7 weeks, increased as initial Zn concentration of nutrient solution increased from deficient (0 added Zn) to 4uM added Zn. A maximum average leaf Zn concentration of 27.2 ug Zn/g dw occurred at 4uM added Zn with high initial nutrient solution P concentration (5.32 mM). However, average mid terminal leaf P concentrations decreased from 0.72% to 0.37% as initial Zn increased to 4uM added Zn at high P, suggesting the possibility of P toxicity when Zn supply in nutrient solution was inadequate.

In the Pacific Northwest, including southern British Columbia, Zn nutrition can be a concern in apple orchards (7). Annual applications of dormant $ZnSO_4.7H_2O$ are recommended and made in many local orchards as a consequence of apparently inadequate leaf Zn concentrations for mid terminal new years extension leaves uncontaminated by Zn sprays. Leaf Zn concentrations usually average less than 20 mg Zn/kg dw and often less than the 14 mg Zn/kg dw considered deficient in the world literature (11). Despite the apparent marginal leaf Zn nutrition in so many orchards, little research has been performed to investigate factors affecting leaf Zn concentration since original recognition of the Zn deficiency problem in British Columbia (14). For example, the interaction of Zn and P has frequently been recognized and investigated for agronomic crops (8) but has had little attention in tree fruits despite a recent hypothesis that Zn deficiency can result in lack of regulation of P uptake with eventual P toxicity symptoms for plants growing in nutrient solutions (5). In part, the lack of investigation of Zn-P interactions reflects previous research in the Pacific Northwest which indicated little need to consider the P nutrition of mature apple trees (1, 13). Recent research has, however, indicated situations where P fertilization, especially when replanting, may be advantageous (10, 12) implying a future need to re-evaluate Zn with respect to P nutrition. For these reasons, three laboratory experiments were initiated in order to investigate leaf Zn concentration of 'McIntosh' seedlings grown in nutrient solutions of apparently inadequate Zn, and under conditions of a range of Zn and P concentrations in nutrient solution.

Three different laboratory experiments were performed using open-pollinated 'McIntosh' which were germinated in flats containing a sterile 2 vermiculite: 1 perlite mixture. After transplanting and randomisation in the appropriate nutrient solution at the 2-4 leaf stage

The authors acknowledge the technical assistance of W. Peters and M. Schulze.
[1]Research Scientists

(about 3 weeks), seedlings were subsequently grown with aeration under 16-hr day length greenhouse conditions during the November to March period. Supplemental light (400-700 nm) was provided by 40-w cool-white fluorescent and 60-w incandescent light (80:20) to produce a minimum of 100 uE/s/m^2 at the crop canopy. Greenhouse temperatures ranged from 18°+ 1°C (night) to 24° + 2° (day).

In experiment 1, uniform seedlings were transferred into 1-litre containers of Long Ashton nutrient solution (4) minus-Zn and allowed to grow for 1 month prior to harvest at about the 10 leaf stage, about 1 week after Zn deficiency symptoms were first observed. Nutrient solution was replenished once during this period. Bloc (a (2-chrophenyl)-a (4-chlorophenyl)-5- (pyrimidine methanol) was also applied for mildew control. At harvest, 8 replicates of 6 seedlings were partitioned into cotyledons, other leaves, stems and roots which were oven-dried overnight at 65°C, weighed, ashed at 475°C for 3 hr prior to uptake in 0.5 M HCl, and determination of Zn by atomic absorption spectrophotometry. Zn was similarily determined on 10 lots of 20 seeds minus seed coats.

In experiment 2, 40 uniform seedlings were transferred into each of otherwise normal 3 litre Long Ashton nutrient solutions containing minus-Zn, 0.1 uM, 1.0 uM (normal) or 4.0 uM added Zn. After 3 weeks of growth, 10 seedlings at each Zn concentration were sprayed to runoff, avoiding Zn contamination of the bathing solutions, with either distilled water (0 Zn) or 2.0 x 10^3 ug Zn/ml as $ZnSO_4.7H_2O$, chelate A (lignosulfonic chelated Zn, Nutraplex, 10% Zn, Valley Zn Corp.) or chelate B (phenolic chelated Zn, This, 7% Zn, Stoller Chem. Co.). The seedlings were allowed to grow an additional month in their respective nutrient solutions during which time approximately 1 litre of KNO_3 solution (.404g KNO_3/litre) was added to avoid the occurrence of K or N limited growth. At harvest, shoot length was measured on 8 replicates (eliminating the tallest and shortest seedling in each of the 4 x 4 treatments). Zn concentration was also determined as previously described on three mid-shoot leaves per seedling from above the point of foliar Zn application.

In experiment 3, 10 uniform seedlings each were randomly transferred into otherwise normal Long Ashton nutrient solution containing all possible combinations of P concentrations at 1/4 normal (0.33 mmP) or 4 x normal 5.32 mmP) and 3 Zn concentrations (0, 1.0, 4.0 uM added Zn). Seedlings grew in the respective nutrient solutions for 5 1/2 weeks during which time solutions were replenished twice with distilled water and a single spray of Bloc was applied to control mildew. Nutrient solutions were thus typical of standard nutrient culture systems where the initial fixed Zn or P concentration declined with plant growth. At harvest growth parameters including shoot length and top and root dry weight were measured on 8 replicates per treatment. Also 3 or 4 (if leaves were small) mid-shoot leaves per seedling were oven dried at 65°C and a 250-mg subsample was digested for 0.5 h on a block digester at 400°C prior to P determination using standard autoanalyzer techniques. The remainder of the leaf sample was ashed at 475°C prior to determination of Zn concentration as previously described.

Zn concentration of 'McIntosh' seeds without seed coats are higher than most leaf samples in the field, averaging 45.1 ug/g (Table 1). Upon

appearance of Zn deficiency symptoms (at the 10 leaf stage) after growth in 1 litre of apparently Zn-free Long Ashton solution cotyledons still averaged 34.5 ug Zn/g while stems, leaves and roots had low Zn concentrations. The average leaf Zn concentration of 8.5 ug/g, for example, is well below the 14 ug Zn/g concentration at deficiency reported for mid terminal apple leaves in the literature (11). Calculation of absolute amounts of Zn contained in seedlings also indicate that, on average, 60% of the mass of Zn is contained within leaves where most of the dry matter has been produced. It would thus appear that under conditions of seedling growth in minus Zn solutions, the bulk of available Zn is transported to the leaves. Furthermore, for this experiment, the average absolute Zn contained within seedlings exceeded that contained in the average seed by 9 ug. Thus, it is apparent that additional Zn is available to seedlings in 'minus-Zn' Long Ashton solution. As indicated by Hewitt (4) contamination by use of unpurified reagents (as in our experiment) is often a major source of such Zn. Since the Long Ashton solution used required the addition of approximately 2.5 g of reagents, an average reagent concentration of 3.6 ug/g would be sufficient to result in the accumulation of the additional 9 ug Zn. However, despite the additional Zn, Zn deficiency symptoms still occurred in 'McIntosh' seedlings after a month. It was thus possible to achieve inadequate leaf Zn concentration in nutrient solution through the use of reagent grade chemicals despite the existence of a certain amount of Zn contamination, likely from the chemicals.

In experiment 2, leaf Zn concentration was significantly increased by either increasing the Zn concentration of the nutrient solution or by foliar sprays of chelated or mineral $ZnSO_4$ at a 2,000 ug Zn/ml concentration after 3 weeks of growth in their respective nutrient solutions (Table 2). In both situations, increases in leaf Zn concentration were associated with significant growth responses as Zn available to the seedlings increased (data not shown). The growth response in the range from 0 to 4 uM added Zn suggests that the optimum concentration of Zn in solution necessary for apple seedlings may be similar to values reported in the 0.3 to 3.0 uM range for other plants (4). Although Zn supply in standard nutrient culture systems is similar to a soil with a given Zn concentration but limited Zn buffering capacity (3), these results also suggest that apples should be responsive to variations in availability of soil solution Zn. Improved understanding of an orchard's Zn status may thus await development of an appropriate soil test for assessing soil Zn supply.

Although leaf Zn concentration increases were measured for the 3 foliar sprays of Zn averaged over the various solution Zn concentrations, the increases were not as great as were achieved by seedlings growing in 4 uM Zn solutions when averaged over all foliar sprays. This suggests that foliar sprays augmented leaf Zn concentration but did not result in the highest leaf Zn concentration which was achieved in nutrient solutions with 4 uM added Zn. Greater response of leaf Zn concentration of apple trees to soil applied $ZnSO_4$ when root growth was stimulated (by cutting roots) when compared to a number of foliar sprays has also been reported under field conditions (9).

In experiment 3, a significant interaction was measured between solution Zn and P concentrations for all seedling growth parameters except root harvest dry weight, which was also unaffected by variation in Zn or P concentration (data not shown). Growth responses were similar in pattern to those measured for plant height (Fig 1a). Plant height at harvest increased as initial Zn concentration increased from 0-4 uM added Zn at both high (P2) and low (P1) P concentrations in nutrient solution. However, there was a greater growth response at P1 than at P2 over the range of added Zn. This was a consequence of greater seedling growth at 0 added Zn at P2 while growth was greater at P1 at 4 uM added Zn. It is not known why growth was significantly greater at P2 with no added Zn, although as was measured in experiment 1, it is possible that minor amounts of Zn sufficient to promote additional growth may have been contained in the additional 2.34 g $Na\ H\ PO_4.2H_2O$ required per 3 litres of nutrient solution for the P2 treatment. However, the relative reductions in seedling growth at P2, as statistically apparent at 4 uM Zn are consistent with recent research which suggested the possibility of P accumulation and toxicity in 'Emerald' Okra (Abelmoschus esculentus (L) Moench) grown in nutrient solution at low Zn levels (6).

Mid terminal leaf P concentrations for the 'McIntosh' seedlings also paralleled results for okra with leaf P averaging 0.72% at P2 and 0.42% at P1 with 0 added Zn but only 0.37% and 0.17% respectively at 4 uM added Zn (Fig 1b). It thus seems, as was reported by Loneragan et al for okra (6), that conditions of inadequate Zn supply in nutrient solution lead to extreme accumulation of P in apple leaves. At 0 added Zn, for example, leaf P/Zn ratios for the seedlings averaged 1182:1 at P2 and 693:1 at P1 while similar ratios at 4 uM added Zn were 141:1 and 108:1. Furthermore, some margin leaf necrosis was observed in basal leaves of 7 P2 seedlings in the experiment whose mid terminal leaf P concentrations rangef from 0.34% to 0.76%. In several plants, not including apple Loneragan et al (6) reported plants with symptoms attributed to P toxicity had P concentrations ranging from 0.8 to 3% in their shoots and from 1.2 to 4.5% in their leaves. These values are higher than our apple leaf P concentrations although no P measurements were made on the basal leaves which exhibited most severe marginal leaf necrosis.

There was a significant interaction between P and Zn levels for leaf Zn concentration of the same mid terminal leaves (Fig 1b). Leaf Zn at 0 added Zn was not significantly different at P1 and P2. The small increase in leaf Zn concentration at 1 uM Zn, P1 is a partial reflection of the dilution effect previously reported for leaf Zn (7) since the large dry matter increase for P1 between 0 and 1 uM added Zn resulted in a lower leaf Zn concentration than might otherwise be expected. However, leaf Zn concentration of the sampled leaves was significantly higher at P2 with 1 and 4 uM added Zn. This increase was greater than would be expected as a consequence of the growth reductions at P2, 4 uM Zn. Although no measurements were made of total plant uptake of Zn in our experiments, the behaviour of leaf Zn concentration contrasts with that reported by Loneragan et al (6) where high P (2mM P) had little or no effect relative to low P on Zn concentration of the various plant parts over a range of available Zn. In general, however, for agronomic crops, some experiments have reported a decrease in Zn concentration in plant tissue as a result of P fertilization although this does not always occur (2). However, for mid

terminal apple leaves in this experiment, the average leaf Zn concentration at P2 with 4 uM added Zn was 27.2 ug Zn/g dw, much higher than is generally reported for apple leaves that have not been contaminated by Zn sprays in orchards in southern British Columbia. Although the caution necessary in extrapolation of results from artificial growth systems to field situations has been well recognized for Zn (3), these results suggest investigations of leaf P/Zn ratios in orchards should be undertaken to determine the nature of P-Zn relationships in field situations where soil solution P concentrations are so much lower and many apple trees are infected with vesicular-arbuscular mycorrhizae.

In summary, these laboratory experiments have shown that it is possible to achieve Zn-deficiency symptoms and relatively low mid terminal leaf Zn concentrations for 'McIntosh' seedlings raised in a minus-Zn (0 added) Long Ashton solution comprised of reagent grade but unpurified chemicals. Mid terminal leaf Zn concentration of the seedlings could however be increased as the initial concentration of added Zn increased through the range 0 to 4 uM Zn and was highest for seedlings growing in solutions of both high Zn and P concentration. Furthermore, the experiments have demonstrated the possibility of P toxicity induced by inadequate Zn nutrition. The response of apples in the field to soil Zn levels and to a possible P-Zn interaction seem to be two areas of profitable future research, especially since P application at planting time has been gaining increased popularity with orchardists.

LITERATURE CITED

1. Benson, N.R. and R.P. Covey. 1979. Phosphorus nutrition of young 'Golden Delicious' apple trees growing in a gravel culture. J. Amer. Soc. Hort. Sci. 104: 682-685.

2. Brown, A.L., B.A. Krantz and J.L. Eddings. 1970. Zinc-phosphorus interactions as measured by plant response and soil analysis. Soil Sci. 110: 415-420.

3. Carroll, M.D. and J.F. Loneragan. 1968. The relevance of solution culture studies to the absorption of zinc from soils. Int. Cong. Soil Sci., Trans. 9th. (Bucharest, Romania) II: 191-202.

4. Hewitt, E.J. 1966. Sand and water culture methods used in the study of plant nutrition. Technical Comm. 22. Commonwealth Bureau of Horticulture and Plantation Crops, East Malling, Maidstone, Kent.

5. Loneragan, J.F., T.S. Grove, A.D. Robson and K. Snowball. 1979. Phosphorus toxicity as a factor in zinc-phosphorus interactions in plants. Soil Sci. Soc. Am. J. 43: 966-972.

6. Loneragan, J.F., D.L. Grunes, R.M. Welch, E.A. Aduayi, A. Tengah, V.A. Lazar and E.E. Cary. 1982. Phosphorus accumulation and toxicity in leaves in relation to zinc supply. Soil Sci. Soc. Am. J. 46: 345-352.

7. Neilsen, G.H. and E.J. Hogue. 1983. Foliar application of chelated and mineral zinc sulphate to Zn-deficient 'McIntosh' seedlings. HortScience 18: 915-917.

8. Olsen, S.R. 1972. Micronutrient interactions. p. 243-264.In J.J. Mortvedt et al (ed) Micronutrients in agriculture. Soil Sci. Soc. of Am., Inc., Madison, Wis.

9. Orphanos, P.I. 1982. Spray and soil applications of zinc to apples. J. of Hort. Sci. 57: 259-266.

10. Raese, J.T., D.C. Staiff and D.R. Visser. 1984. Effect of nitrogen and phosphorus on 'Delicious' apple trees grown in caliche soil in the greenhouse. J. Plant Nutr. 7: 1433-1442.

11. Shear, C.B. and Faust, M. 1980. Nutritional ranges in deciduous tree fruits and nuts. Hortic. Rev. 2: 142-163.

12. Slykhuis, J.T. and Li, T.S.C. 1985. Responses to soil disinfectants and phosphate fertilizers in apple replant problem soils in British Columbia. Can. J. Plant Path. (in press).

13. Wilcox, J.C., B. Hoy and R.C. Palmer. 1947. Orchard fertilizer tests in the Okanagan Valley. Sci. Agric. 27: 116-129.

14. Woodbridge, C.G. 1951. A note on the incidence of zinc deficiency in the Okanagan Valley in British Columbia. Sci. Agr. 31: 40-41.

Table 1. Mean and standard deviation of concentration and absolute amount of zinc contained in McIntosh seeds and in various portions of 'McIntosh' seedlings with Zn deficiency symptoms as raised in minus-Zn solution.

	Mean and standard deviation of Zn concentration (ug/g)	Mean and standard deviation of absolute amount of zinc (ug)
I Seed[z]	45.1 ± 3.5	1.3 ± 0.4
II Seedlings with Zn deficiency symptoms[z]		
Cotyledon leaves	34.5 ± 5.5	0.6 ± 0.1
other leaves	8.5 ± 1.4	6.3 ± 1.4
stems	5.4 ± 0.6	1.4 ± 0.2
roots	7.1 ± 1.3	2.0 ± 0.3

[z] means, standard deviation of 10 lots of 20 seeds without seed coats.
[y] means, standard deviations of plant parts from 8 replicates of 6 seedlings each.

Table 2. Leaf Zn concentration of 'McIntosh' seedlings averaged by zinc concentration of Long Ashton solution and by foliar spray treatment.

Zn content of growing medium	Leaf Zn concentration ug/g	Foliar spray[z] treatment	Leaf Zn concentration ug/g
1. 0 added Zn	13.5	1. distilled water	13.2
2. 0.1 uM Zn	14.1	2. $ZnSO_4$	18.9
3. 1 uM Zn	16.2	3. Chelate A	17.0
4. 4 uM Zn	22.6	4. Chelate B	17.5
standard error =	0.7	standard error =	0.7

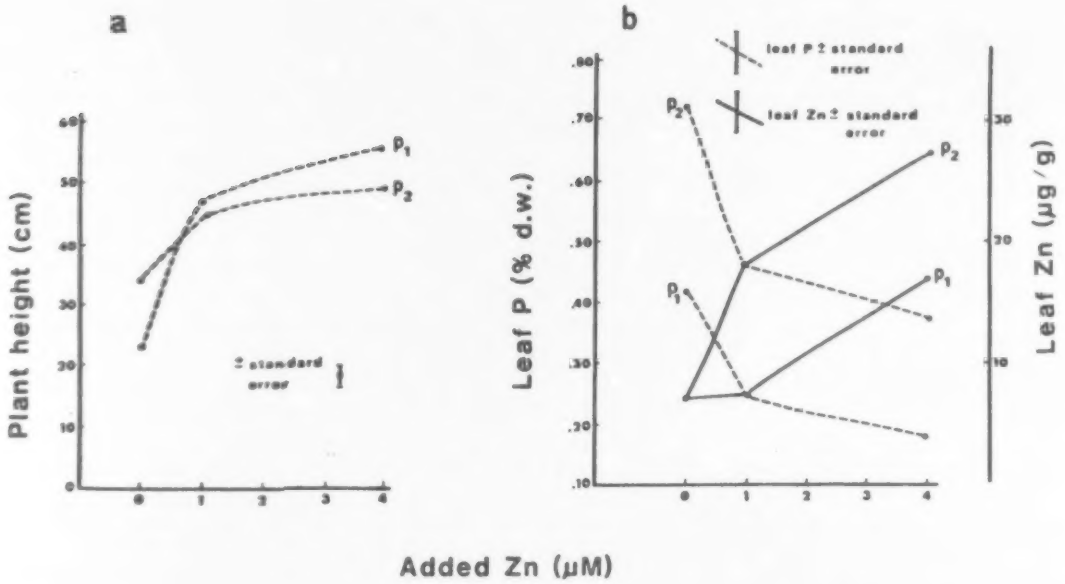
Analysis of variance

Source of variation	df	Mean square
Replicates	7	14.98 NS
Zinc content of growing medium (Zn)	3	507.34**
Foliar spray treatment (S)	3	180.84**
Zn x S interaction	9	14.35 NS

[z] All sprays, except distilled water, made at the same Zn concentration of 2.0×10^3 ug Zn/ml.

LIST OF FIGURES

Figure 1. Plant height (a) and leaf Zn and P concentration (b) of McIntosh' seedlings growing for 5 1/2 weeks at 3 Zn levels under low P (P1, 0.33 mM) or high P (P2, 5.32 mM) concentrations.



^{15}N TRACER METHODOLOGY IN SOIL RESEARCH

PATRICK C.K. PANG
Canadian Forestry Service, Pacific Forest Research Centre
506 West Burnside Road, Victoria, B.C., V8Z 1M5

INTRODUCTION

Nitrogen-15 tracer methodology is the most sensitive and precise tool for studying the dynamics of nitrogen cycling and plant utilization of N-fertilizers in soil-plant ecosystems. Nitrogen-15 is a stable isotope and is non-radioactive. Therefore ^{15}N-labeled chemicals do not have a half-life as do the radioactive chemicals. The most abundant stable N isotope is ^{14}N (99.633 atom % ^{14}N) and the other is ^{15}N (0.367 atom % ^{15}N). The radioactive nitrogen isotope which has been used in soil research is ^{13}N which has a half-life of 10 minutes. Although ^{15}N chemicals are expensive, ^{15}N tracer experiments are cost-effective in the long run compared to the "difference" method in which the data obtained from treatments are subtracted from those without treatments.

^{15}N TECHNIQUES

There are three techniques utilizing ^{15}N isotope in soil research: 1) ^{15}N enrichment, (2) ^{15}N depletion and (3) natural variation of ^{15}N. There are limitations in using ^{15}N depletion and natural variation of ^{15}N in studying the dynamics of nitrogen transformations and plant utilization (Olson, 1979). The ^{15}N enrichment technique is the most commonly used of the three for any precise measurements.

Experiments using ^{15}N are easy and simple but time-consuming. However, a mass spectrometer is required for the precise determination of isotopes ^{15}N and ^{14}N. Optical emission spectrometry is an alternative which is not as precise as mass spectrometry.

^{15}N ANALYSIS

In an experiment in which soil and plant were supplied with enriched ^{15}N labeled fertilizer, plant and soil were destructively sampled, dried and ground homogeneously for chemical analysis. The analysis of ^{15}N samples involved the following steps (IAEA/FAO Technical Report, 1976):

I. Quantitative determination for N
   A. (i) Total-N by micro-Kjeldahl digestion to convert organic-N to ammonium-N, and/or
      (ii) Inorganic-N (NH_4^+, NO_2^- and NO_3^-) by extraction with 2N KCl.
   B. Steam-distillation
   C. Titration

II. Acidification of distillate after the titration with 0.1 N HCl or 0.1 N H_2SO_4 and condensation of the solution to dryness.

III. Conversion of distillate containing NH_4^+-N to N_2 under high

vacuum with LiOBr after the sample was degassed.

IV. Mass spectrometric analysis for ^{14}N and ^{15}N.

CALCULATIONS

The abundance of ^{15}N is expressed as atom percent ^{15}N and is calculated as follows: Atom % $^{15}N = \frac{100}{2R + 1}$ where R is the isotope ratio of $^{14}N^{14}N/^{14}N^{15}N$. The degree of enrichment of stable isotope in a given sample is expressed in atom % ^{15}N excess which is the enrichment of a sample above that of natural abundance (0.367 atom % ^{15}N). With these definitions in mind, the recovery of fertilizer-N added as ^{15}N-labelled fertilizers could be calculated:

Percent recovery of applied-N from a sample =

$$\frac{\dfrac{(\text{Atom \% } ^{15}\text{N excess})_{\text{sample}}}{(\text{Atom \% } ^{15}\text{N excess})_{\text{fertilizer}}} \times 100 \times (\text{mg N in sample})}{(\text{mg N fertilizer applied})}$$

REFERENCES

IAEA/FAO Technical Report #171. 1976. Soil and fertilizer nitrogen In Tracer Manual on Crops and Soils. p. 139-148. Vienna, Austria.

Olson, R.A. 1979. Isotope studies on soil and fertilizer nitrogen. In Isotope and Radiation in Research on Soil-Plant Relationship. IAEA/FAO. Vienna, Austria. pp. 3-31.

ADVANTAGES OF ^{15}N TECHNIQUES IN INTERPRETING DATA FOR SOIL RESEARCH

C.G. Kowalenko
Agriculture Canada, Research Station,
Agassiz, B.C.

GENERAL COMMENTS

The nitrogen cycle

Before considering the use of ^{15}N in soil research, it may be useful to review the entire nitrogen cycle (Figues 1). Without getting bogged down with details, only some general comments will be made. The nitrogen cycle

a) is complex
Nitrogen is present in many forms whose quantitative and qualitative characteristics change at various rates in response to a variety of processes.

b) is dynamic
Physical, physical-chemical, chemical and microbiological processes are continually at work in response to a variety of environmental factors.

c) is global in scope
Nitrogen present in soil, air and water, interacts on a global scale.

d) has wide ranging implications
The implications affect:
(i) life (both plants and animals)
(ii) energy (such as fertilizer manufacture)
(iii) health (affects water as with NO_3 content and air as with N_2O effect on ozone layer)

The advantages of ^{15}N use

The general advantages for use of ^{15}N include:

(a) It is a non-radio-active tracer (no special safety requirements)

(b) It is readily available (in many forms and "strengths")

(c) Methodology is well worked out

(d) It is cost effective
(i) In many cases it is the only way to study a system (may be the only way to rigorously test simulation models)
(ii) More can be learned in a shorter time because basic processes can be studied.

Precautions for ^{15}N use

Costs for ^{15}N products and for analyses are relatively high. It is essential that experiments using it are well designed and conducted (i.e.) careful control of the experiment and the analyses.

ILLUSTRATION OF ^{15}N USEFULNESS

The main advantage of the use of ^{15}N over non-tracer methods is that basic nitrogen processes such as denitrification, immobilization, mineralization, N_2 fixation and clay fixation can be examined in more detail and more individually distinguished. To illustrate the advantages of ^{15}N in soil research I will show some results from work I was involved in at Ottawa between 1974 and 1978. I will only focus on one part of the work, namely fixation of NH_4 by clay. I chose fixed NH_4^+ since it serves to illustrate my point well and also to alert you of a soil nitrogen fraction that has largely been ignored.

Before we examine the information on fixed NH_4, I will briefly outline the field experimental method. In order to use ^{15}N efficiently, I opted to use what I call microplots. These are simply soil columnms confined in open-ended cylinders directly in the field. The cylinders limit any lateral movement of water giving a controlled system to facilitate fairly accurate determinations of mass balance of nitrogen. With certain assumptions, which I feel are quite valid, denitrification vs leaching losses from a defined soil profile depth can be differentiated using these microplots. The microplots should simulate field conditions relatively well.

Initial non-tracer work showed that the soil studied in Ottawa, named Bainesville, contained a fair amount of clay fixed NH_4 and also fixed a fair amount of NH_4 added to it. It also appeared that, once NH_4 was fixed by the clay, it was released quite slowly. Early mathematical modelling (Figure 2) incorporated the assumptions that:

(a) fixed NH_4 is a distinct and uniform unit
(b) fixation and release of fixed NH_4 are physical-chemical processes
(c) fixation proceeds quite rapidly
(d) release of fixed NH_4 is fairly slow.

This model system, which was developed around and tested by a laboratory incubation experiment, appeared to be quite valid. However, with non-tracer measurements, the model could not be rigorously tested. Non-tracer studies were plagued by weaknesses in the analyses of fixed NH_4. These weaknesses were:

(a) a large error of determination (fixed NH_4 measurement is complex and tedious)
(b) a relatively large background against which small changes cannot be detected
(c) only net changes could be measured (cannot differentiate new fixation from exchange of fixed NH_4)

A series of ^{15}N studies showed that basic assumptions of the fixed NH_4 fraction were not correct

(a) Particle size study

Non-tracer analyses showed that soil particles larger than clay contained fixed NH_4 (Table 1). Tracer studies further revealed that each particle size fraction varied in the amount they fixed upon addition of NH_4. Also, the results showed that release of this recently fixed NH_4 from the fractions varied and that the release rate from each fraction varied depending on presence or absence of plant growth. Besides showing that initial assumptions about the fixed NH_4 fraction are now in doubt, these results illustrate the greater understanding that tracer methods can provide about soil processes.

(b) Brookston soil

A small laboratory study of a different agricultural soil in Ontario, Brookston, showed that under certain circumstances NH_4 added to a soil not only increases the total amount of fixed NH_4 but can also exchange with fixed NH_4 already present in the soil (Table 2). In the two surface samples tracer data showed that a higher amount of added NH_4 was fixed than was measured by non-tracer methods. The subsurface sample results suggests that this was not a methodological anomally.

(c) N-serve results

N-serve is a product that was developed as a potential method of using fertilizer and to some extent soil nitrogen more efficiently. The chemical fairly selectively stops the conversion of NH_4 to NO_3, which would hence reduce denitrification and leaching losses from the soil. Many studies have been done to test the practical application of this product during plant production and variable results have been recorded. There have been increased and decreased yields besides no yield differences recorded and in most cases the reason for the results was unknown.

A study examining the relative effectiveness of nitrogen utilization for crop production in a soil known to fix NH_4 was studied in Ottawa (Table 4). In this study, ammonium fertilization in the presence of N-serve did not chage a barley crop yield relative to a non-nitrogen fertilized treatment yet ammonium without N-serve did increase yield. This difference was reflected in plant uptake of nitrogen. Tracer data showed that less of the added NH_4 was fixed in the N-serve than in the NH_4-only treatment and that the NH_4 recently fixed in the clay was much more resistant to release with N-serve than without it.

In summary, I hope this very brief report shows that soil research using ^{15}N can be cost effective and in many cases the only possible way of understanding why the results occurred the way they did with respect to nitrogen.

SOURCES OF EXAMPLES

KOWALENKO, C.G. and D.R. CAMERON. 1976. Nitrogen transformations in an incubated soil as affected by combinations of moisture content and temperature and adsorption-fixation of ammonium. Can. J. Soil Sci. 56: 63-70.

CAMERON, D.R. and C.G. KOWLENKO. 1976. Modelling nitrogen processes in soil: Mathematical development and relationships. Can. J. Soil Sci. 56: 71-78.

KOWALENKO, C.G. 1978. Nitrogen transformations and tansport over 17 months in field fallow microplots using ^{15}N. Can. J. Soil Sci. 58: 69-76.

KOWALENKO, C.G. and D.R. CAMERON. 1978. Nitrogen transformations in soil-plant systems in three years of field experiments using tracer and non-tracer methods on an ammonium-fixing soil. Can. J. Soil Sci. 58: 195-208.

KOWALENKO, C.G. and G.J. ROSS. 1980. Studies on the dynamics of "recently: clay-fixed NH_4^+ using ^{15}N. Can. J. Scoil Sci. 60: 61-70.

KOWALENKO, C.G. 1981. Effect of immobilization on nitrogen transformations and transport in a field ^{15}N experiment. Can. J. Soil Sci. 61: 387-395.

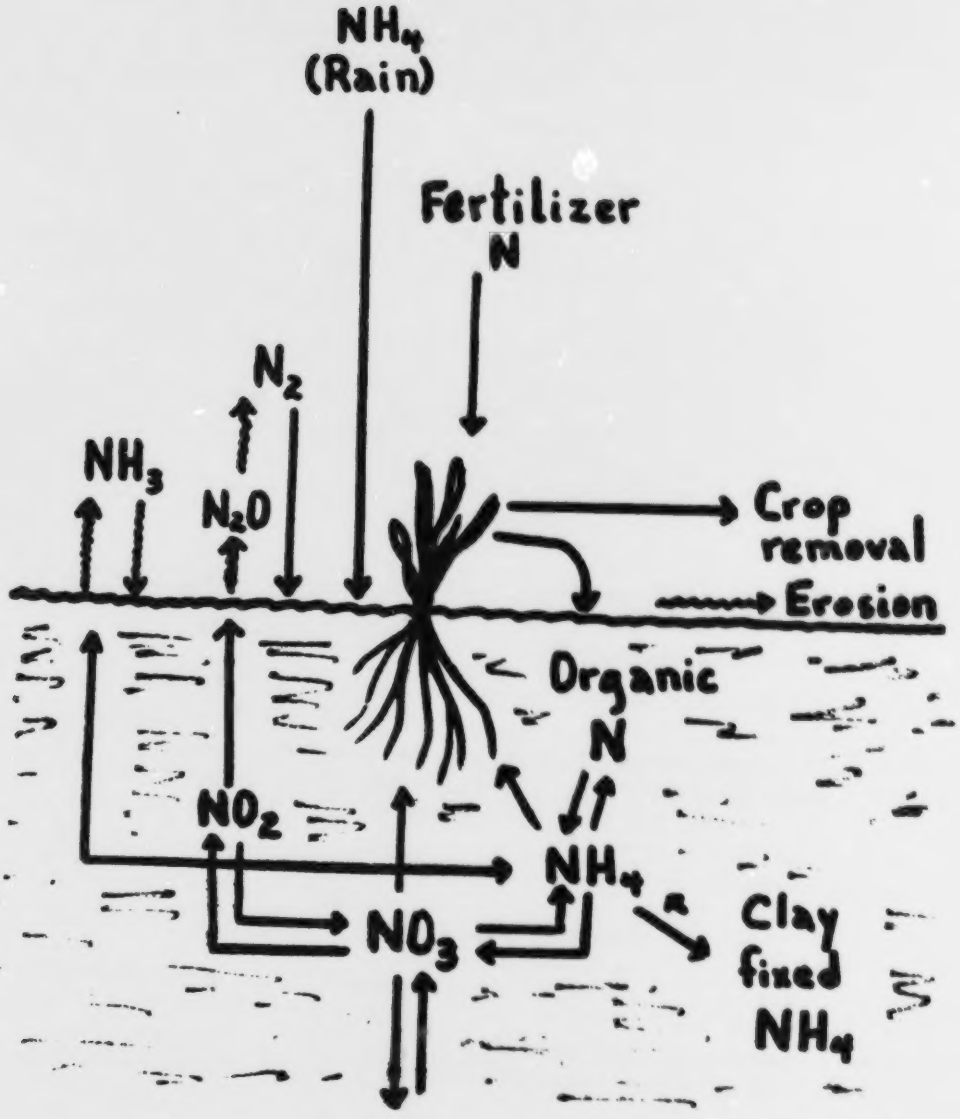


Figure 1. Soil nitrogen cycle

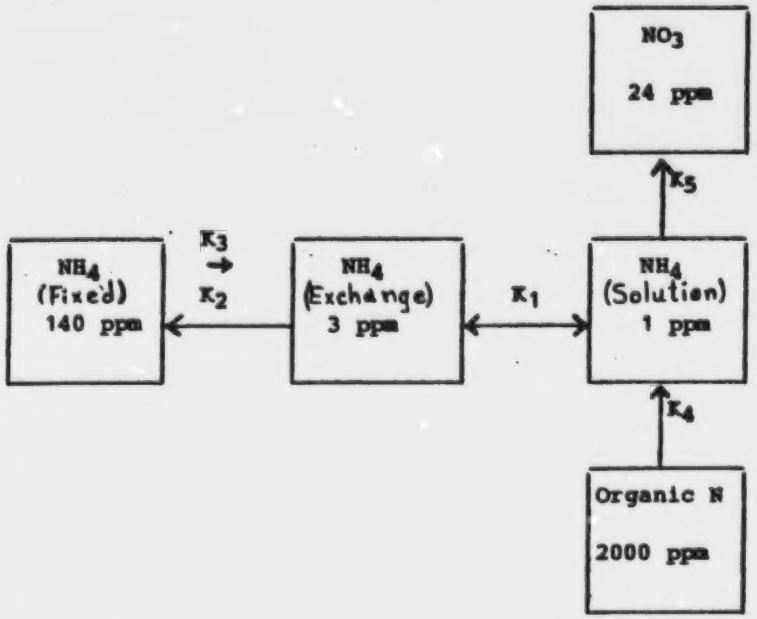


Figure 2. Simplified compartment model of nitrogen transformations in a non-leaching, non-denitrifying soil laboratory incubated experiment.

Table 1. Illustration of the variety and dynamics of "clay-fixed" ammonium pools from a field experiment conducted on Bainesville soil in Ottawa where 152 kg ammonium N/ha was applied

Particle size fraction	Native fixed ammonium	Recently fixed ammonium (by tracer method)		
		Initial	Decrease after 3 months	
		(19 June 74)	Fallow	Barley
-- μm --	-------- kg N/ha ------		--------- % ---------	
<0. 2	72	2.1	100	63
0.2-2	158	76.6	55	75
2-5	16	5.8	23	85
5-20	7	1.2	18	72
20-50	3	0.3	100	33
>50	6	0.9	75	88
Total	262	86.9	54	80

Table 2. Illustration of exchange of fixed ammonium in Brookston soil(Ontario) by comparing tracer and non-tracer measurements

Depth (cm)	Native fixed ammonium	Recently fixed ammonium	
		Non-tracer	Tracer
	ppm N		
0-10	442	14	54
10-20	356	16	47
60-75	480	70	71

Table 3. Illustration of influence of N-serve on barley growth and on clay-fixation and release of ammonium in a field experiment on Bainesville soil in Ottawa

	Ammonium treatment alone	Ammonium treatment plus N-serve
Increase in yield over non-fertilized treatment	Yes	No
Total above-ground nitrogen uptake by barley (Kg N/ha)	182	92
Ammonium fixed by clay immediately after application (kg N/ha)*	74	51
Decrease in recently clay-fixed ammonium after cropping*	96%	71%

*Measured by tracer technique

COMPARISON OF LABORATORY METHODS FOR EVALUATING PLANT-AVAILABLE SOIL PHOSPHORUS

W. van Lierop

British Columbia Ministry of Agricutlure and Food, Kelowna, B.C. V1Y 4R2

Along with the more common utilization of the Inductively Coupled Argon Plasma Atomic Emission Spectrophotometer (ICAP-AES), which permits the simultaneous (or sequential) determination of most plant nutrients, grew an interest in developing soil fertility assessing procedures which also permit determining the availability of many plant nutrients in a single extract. Accordingly, this study had two principal objectives: 1, evaluate some new extractants which could assess plant-available soil phosphorus along with NO_3, K, Ca, Mg, Na and Zn; and 2, establish the nature of the relationship between the amounts of phosphorus extracted with the new solutions by comparing the amounts extracted with those obtained by more familiar procedures. Such relationships are required for determining the relative precision and applicability of a new extractant for soils having a wide range of chemical properties. Furthermore, these relationships are required to convert existing soil test norms and interpretations to equivalent values necessary to validate a new procedure.

The Bray-P1 and Olsen solutions have been utilized extensively by the Ministry of Agriculture (B.C.M.A.F.) laboratory for assessing plant-available phosphorus levels in British Columbia soils. Although formerly the Bray-P1 solution was used to test all soils, in the last couple of years of its use it had only been employed for testing soils which had a pH (H_2O) of less than 7.5. In fact, soil-test calibration work carried out in the past two decades or so, relied upon this P-extractant to verify or improve soil test norms. Although this extractant, is recognized as among the best and probably is the most widely used P-test in North America, it was developed for use in acid soils. Unfortunately, many calcareous soils in British Columbia contain sufficient residual carbonate to neutralize the acid in the extractant thereby rendering it ineffective. For this reason the Olsen

solution, which is alkaline and remains largely unaffected by the presence of residual carbonate in soils, was utilized to determine the fertility status and fertilizer requirements of soils which had a higher pH value (>7.5).

As a general rule a solution cannot be used to test for plant nutrients that are part of its makeup. Accordingly, a soil test solution containing either ammonium, sulfur or copper cannot be used to test for these plant nutrients in soils. In general this also implies that more plant nutrients can be determined in a test solution which contains fewer ingredients. The Kelowna extractant was formulated, therefore, with an essential minimal number of ingredients (0.25N HOAc+0.015N_4F). Acetic acid was selected because it is strongly buffered which permits it to maintain the required low pH, even on calcareous soils, to enable it to extract similar forms of plant-available phosphorus than the Bray-P1 solution.

LIST OF PROCEDURES TESTED FOR DETERMINING PLANT-AVAILABLE P

Name	Chemical Composition	Extraction Time	Soil/Sol. Ratio
Bray-P1	0.025N HCl+0.03N NH_4F	1-min	1:10% $^{v}/_{v}$
Olsen	0.5N $NaHCO_3$	30-min	1:10% $^{v}/_{v}$
Kelowna	0.25N HOAc+0.015N NH_4F†	5-min	1:10% $^{v}/_{v}$
Kelowna	0.25N HOAc+0.015N NH_4F†	15-min	1:10% $^{v}/_{v}$
Kelowna	0.25N HOAc+0.015N NH_4F†	15-min	1:5% $^{v}/_{v}$
Soltanpour and Schwab	1M NH_4HCO_3+DTPA	15-min	1:5% $^{v}/_{v}$
Bray-P2	0.1N HCl+0.03N NH_4F	1-min	1:10% $^{v}/_{v}$
Mehlich	0.2N NH_4Cl+0.2N HOAc+ 0.015N NH_4F+0.012N HCl	5-min	1:10% $^{v}/_{v}$
Alberta/Miller and Axley	0.05N H_2SO_4+0.03N NH_4F	10-min	1:5% $^{v}/_{v}$

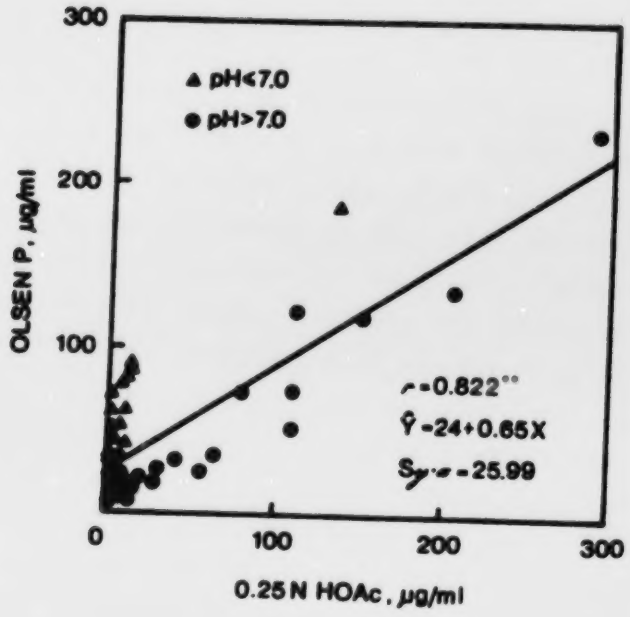
† also verified at 0.5N HOAc with and without NH_4F.

The relative precision and applicability of the verified procedures for determining plant-available P (as well as other plant-nutrients) on acid and alkaline soils was determined by comparing the concentrations that they extracted with those obtained with the Bray-P1 and Olsen solutions by means of regression and correlation techniques. Sixty soils half of which had pH values greater than 7.0 were utilized in comparing the procedures.

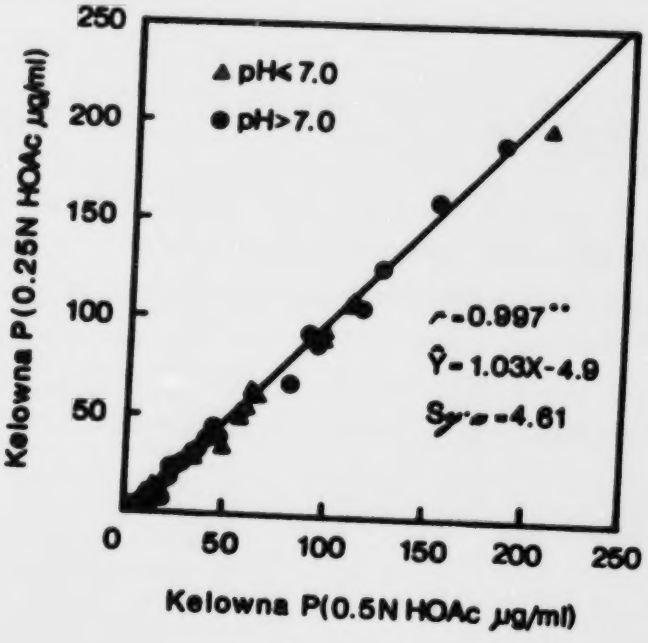
SOIL PROPERTIES:

	Acid Soils	Alkaline Soils
pH (H_2O)	3.6 - 6.0	7.1 - 8.5
O.M. (%)	2.7 - 15.0	0.7 - 17.0
Ca (NH_4OAc; ug/mL)	293 - 2640	2,090 - 12,100
Mg "	21 - 1410	185 - 2,500
Na "	26 - 92	24 - 1,900

Concentrations of soil phosphorus extracted with the Bray-P1 and Olsen procedure were closely related (r=0.91**). However, the regression equation obtained for the relationship ($\hat{Y}$=22.8+1.92X) between the phosphorus values obtained by these methods indicated that the Bray-P1 (Y) extracted about twice as much phosphorus than the Olsen procedure. Acetic acid alone, whether 0.25 or 0.5N, was found unsuitable for assessing plant-available soil phosphorus on acid soils as it was the least precisely related with the amounts of phosphorus removed from soils by either the Bray-P1 or Olsen procedures. Results indicate that acetic acid cannot effectively dissolve Al or Fe phosphates which likely predominate in acid soils. However, acetic acid is rather effective for dissolving Ca-phosphates. This conclusion was suggested by the relatively good relationship obtained between the P-values obtained with acetic acid and the Olsen solution on calcareous soils (Ca-phosphates are assumed to predominate at soil pH values



Relationship between the amounts of P extracted by 0.25N acetic acid and the Olsen procedures on acid and alkaline soils. Note the clustering of P values extracted from acid soils.



Relationship between the amounts of P extracted from acid and alkaline soils using the Kelowna extractant at 0.5 and 0.25N acetic acid. The relationship indicates that 0.25N AA has sufficient acid capacity to maintain the acid medium required for calcareous soils.

higher than 7.0) Apparently, fluoride in a low pH medium is required to extract the same forms of phosphorus from acid soils than the Bray-P1 or Olsen procedures. Accordingly, adding ammonium fluoride (AF;0.015N) to acetic acid (AA) improved the relationship between the amounts of phosphorus extracted from acid soils by it and the standard procedures. The presence of ammonium fluoride did not adversely affect the relationship between P extracted by AA-AF and the standard extractants on soils which had a pH higher than 7.0. Soil solution ratios and extracting times were important in optimizing the relationship between the AA-AF and standard procedures. Accordingly, the relationship between the amounts of phosphorus extracted by the AA-AF mixture and the standard Bray-P1 and Olsen procedures optimized at a soil solution ratio of 1:10 and 5-minute extraction period. Regression information indicated that the relationship between the amounts of phosphorus extracted with the 0.25N AA+015N AF mixture (X) was more precisely related to the amounts extracted by the Bray-P1 ($\hat{Y}$=17+0.92X;r=0.93**;sy.x=22) from acid soils and the amounts of P extracted with the Olsen procedure (Y=0.42X; 0.964**;sy.x=12) from acid and alkaline soils than the two standard procedures were to each other. Since no tested extraction procedure offered

CORRELATION COEFFICIENTS OBTAINED BETWEEN THE AMOUNTS OF P REMOVED FROM SOILS USING EITHER THE BRAY OR OLSEN AND THE TESTED PROCEDURES.

Solutions	Ratio v/v	Time Minutes	Acid Soils		Alkaline Soils
			Bray	Olsen	Olsen
0.5AA+AF	1:5	15	0.84**	0.92**	0.96**
0.24AA+AF	1:5	15	0.83**	0.92**	0.98**
0.5AA+AF	1:5	5	0.89**	0.93**	0.95**
0.25AA+AF	1:5	5	0.88**	0.92**	0.96**
0.5AA+AF	1:10	5	0.96**	0.96**	0.95**
0.25AA	1:10	5	0.96**	0.97**	0.97**
0.5AA	1:5	15	0.68**	0.79**	0.94**
0.25AA	1:5	15	0.64**	0.79**	0.96**
Soltanpour & Schwab	1:5	15	0.87**	0.93**	0.87**
Bray-P2	1:10	1	0.95**	0.95**	0.83**
Mehlich	1:5	15	0.84**	0.92**	0.96**
Mehlich	1:10	5	0.97**	0.97**	0.96**
Alberta/Miller - Axley	1:5	10	0.90**	0.89**	0.88**

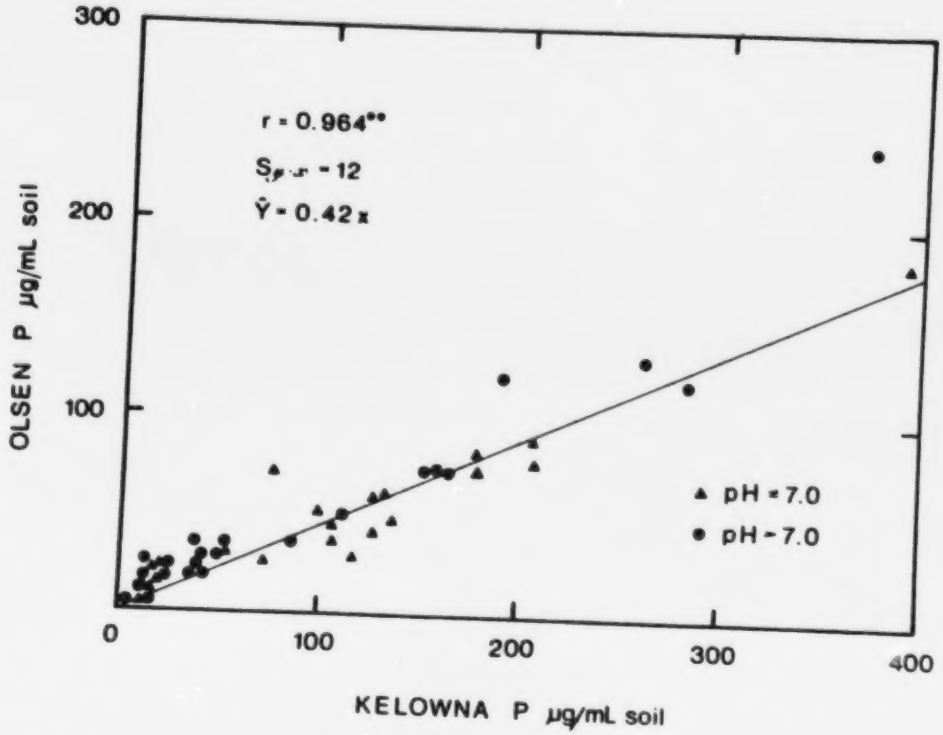


Fig. 3. Relationship between the amount of phosphorus extracted from acid, neutral, and alkaline soils by the Kelowna and Olsen solutions.

advantages over the AA+AF mixture, it has been adopted and named the Kelowna extractant. No practical difference was observed whether 0.5 or 0.25N HOAc was utilized in the Kelowna extractant as regards the amounts of P extracted from acid and alkaline soils but that the relationships with other nutrients were slightly more favourable for the 0.25N HOAc+ 0.015N NH_4F mixture. Therefore, the latter has been retained and utilized since September 1984 to determine the availability of most nutrients by the B.C.M.A.F. laboratory using its ICAP-AES capability.

1985

NINTH B.C. SOIL SCIENCE WORKSHOP

SESSION THREE - How to Deal With Soil Variability

February 22, 1985, A.M.

H. Schreier, Session Chairman

SOIL VARIABILITY: DOES IT INVALIDATE OUR INTERPRETATIONS?

D.E. Moon[1] and H. Schreier[2]

INTRODUCTION

Soil variability is a much discussed, little studied, and even less understood subject in the field of soil interpretation. This is understandable given the complexity of the subject of statistics and the complexity of the soil. Most of our statistical training at university is based on classical parametric statistics. These assume normally distributed data and because so little of our soils data is normally distributed, the tools we were provided with are by and large inappropriate. Ignoring the problem will not make it go away and can lead to serious misinterpretations of our soil data. Awareness of the problem and a little common sense can go a long way towards avoiding the misinterpretation of soils data, if not solving the problem.

We will attempt to portray the nature of the problem and to offer a reasonable solution to one aspect of it, that of the prediction of responses to soil properties over an area of land.

Soil Variability: What is it?

There are basically three kinds of soil variability. They are spatial, temporal, and population variability. We will, for this discussion, ignore sampling and measurement error as sources of variability. Spatial variability is the result of properties changing over distance. To demonstrate this concept Figure 1 is a plot of variance in samples taken over different intervals (ie. ten samples taken within the first 10 m had a variance of 4, ten samples taken within the first 50 m had a variance of 12). In an ideal world of real soil polypedons and soil boundaries, the variance levels off so that larger distances do not significantly increase the variance above that found at shorter distances. When a soil boundary is crossed there is another rapid increase in variance and another leveling off as most of the variability has been accounted for. Such nice curves are not often found in nature but the principle is valid.

Another kind of variability is temporal variability, the change in properties over time. Figure 2 demonstrates this point with a rather idealized curve of a change in some value at successively later points in time. Visualize if you will the influence of an unknown spatial variabiltiy on an attempt to determine temporal variability.

[1] Land Resource Research Institute, Agriculture Canada; [2] Dept. of Soil Science, University of British Columbia.

Figure 1 : SPATIAL VARIABILITY

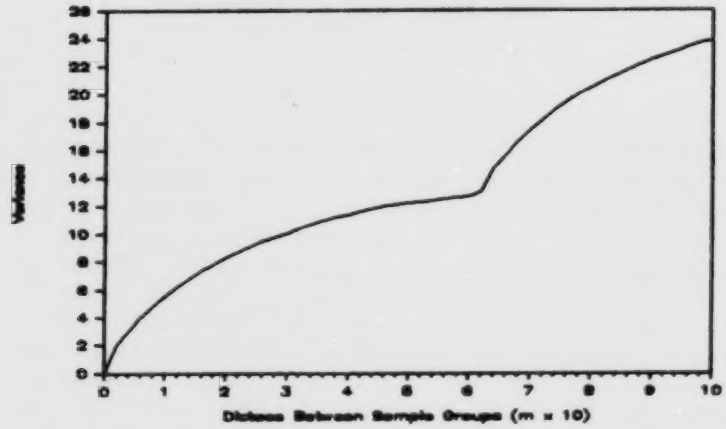


Figure 2: TEMPORAL VARIABILITY

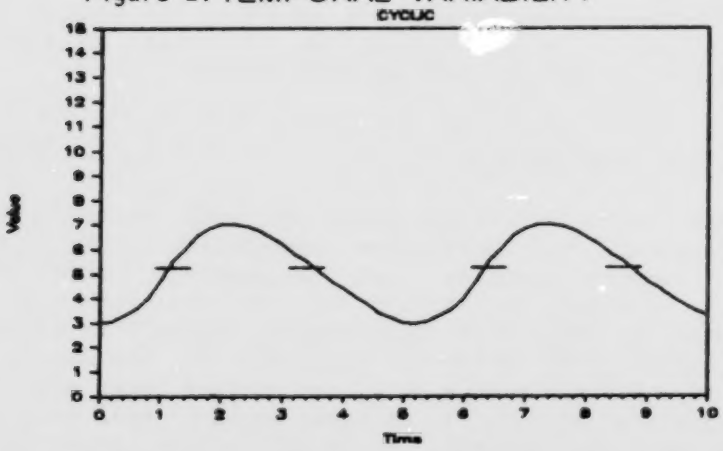
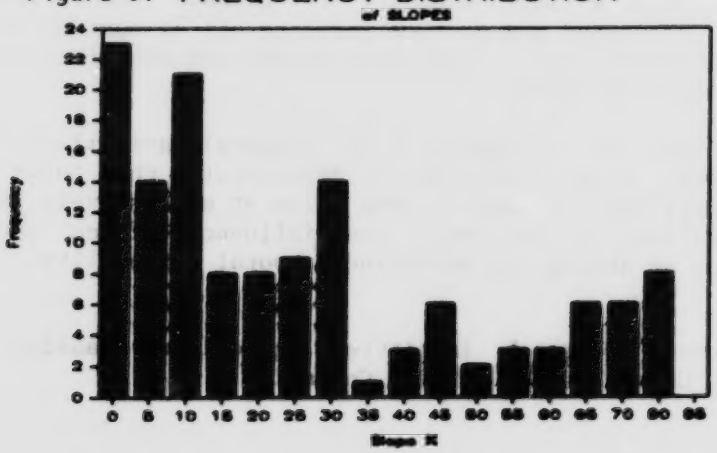


Figure 3: FREQUENCY DISTRIBUTION



The final kind of variability we must cope with is population variability. Population variability comes from the fact that no individual of a species, group, or class is identical to any other individual. Figure 3 presents a frequency distribution which shows the frequency slope classes for 0.1 Ha plots found in a map area. The slope classes 0, 5-15, 20-35, 40-50, and 55-80 correspond to floodplain, fluvial fan, basal slope, and valley side slope landforms. Each landform can be considered a population or the watershed can be considered a population but in either case individual 0.1 Ha plots will show a range of slopes. It is clear that determining temporal variability in a population of highly variable soils sampled at widely separated distances presents a complex problem.

In soils work it is difficult to distinguish between spatial variability and population variability since each member of a class will have associated with it a component of spatial variability. The one advantage we have is that when dealing with an area of land which must be managed as one soil, spatial variability and population variability present the same problem and for practical purposes need not be distinguished. We simply treat the field as a population and each sample as an individual member of the population.

Population Variability

As we mentioned earilier few of our soil properties are normally distributed, in fact few of our soil properties even approximate normality. The following series of frequency distributions (Figures 4a, b, c, and d) show the distributions of % O.M., NO^3-N, Ca, and C.E.C. It is of interest to note that even though the samples were the same for each determination the distributions are dramatically different. Percent organic matter is strongly bimodally distributed, NO^3-N is skewed left, Calcium is skewed left, and Cation Exchange Capacity is approximately normal. Of a total of 7 properties measured only two approximated normal distributions. Figures 5a, 5b, and 5c show rather idealized exaples of the three major types of population distributions.

Figure 5a shows a rather rare pattern, a normal distribution. It is the distribution that we assume all of our properties to have when we perform routine statistical procedures without transforming our data. Much of our data may be approximately normal but by and large we do not verify the distribution before performing analysis.

Figure 5b shows a much more common distribution, a right-skewed distribution. Skewed distributions may be left or right skewed but are always asymetric. If the distribution is known to be skewed it can often be transformed to approximate normality thus making parametric statistical procedures valid. Comparable non-parmetric procedures ,which do not require the data to be normally disributed, are generally available. When the distribution is unknown or transformation is not possible non-parametric procedures should be used.

Figure 5c shows another common distribution, a polymodal distribution. This example is nearly symetrically bimodal but asymetric distributions with more than two peaks are possible. This kind of distribution

Figure 4a:FREQUENCY DISTRIBUTION

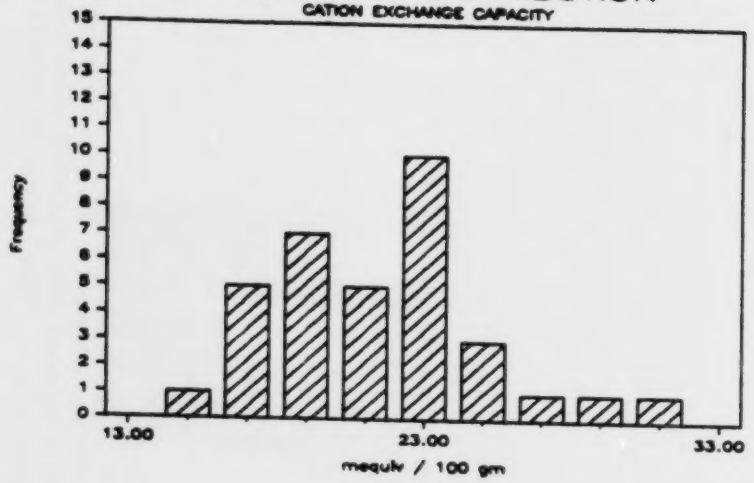


Figure 4b: FREQUENCY DISTRIBUTION

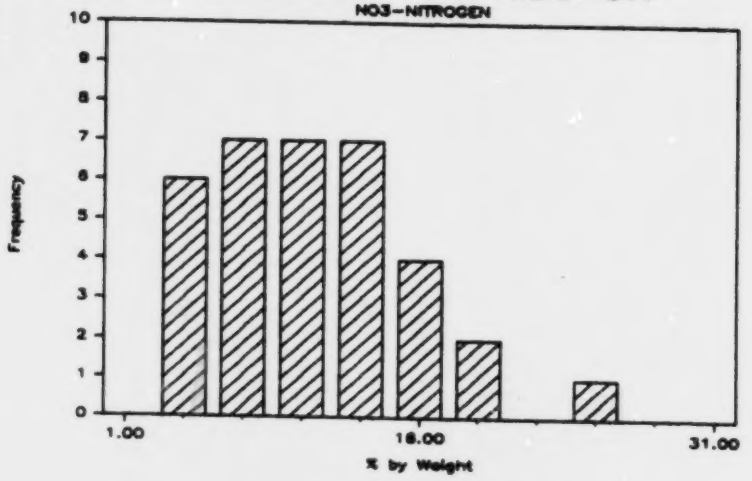


Figure 4c: FREQUENCY DISTRIBUTION

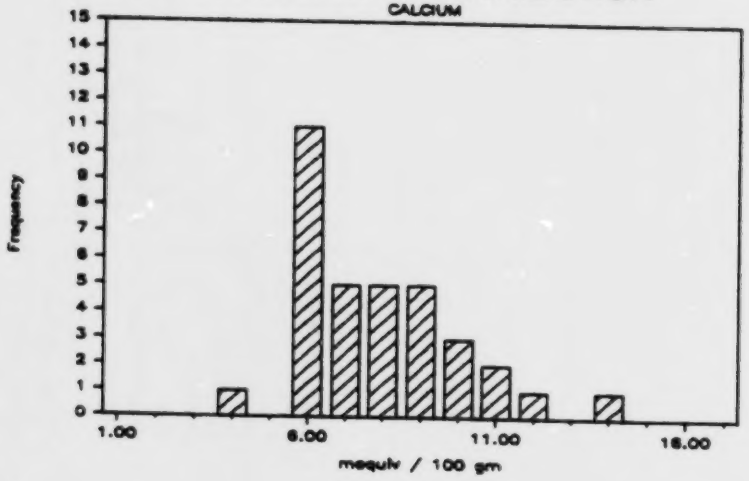


Figure 4d: FREQUENCY DISTRIBUTION

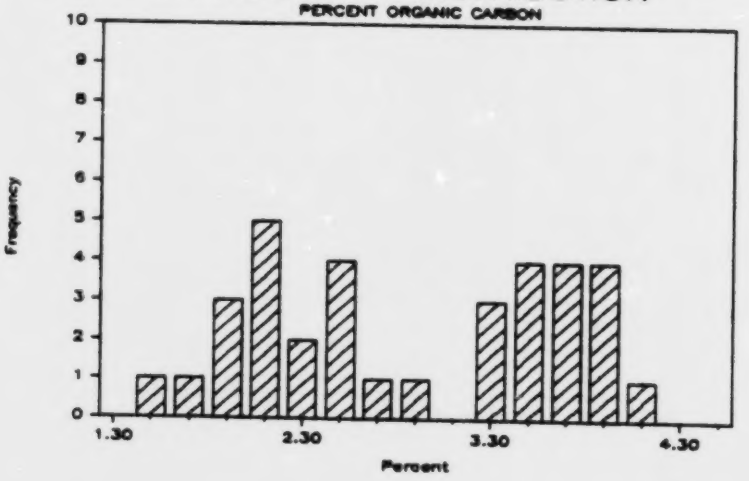


Figure 5a: NORMAL FREQUENCY DISTRIBUTION

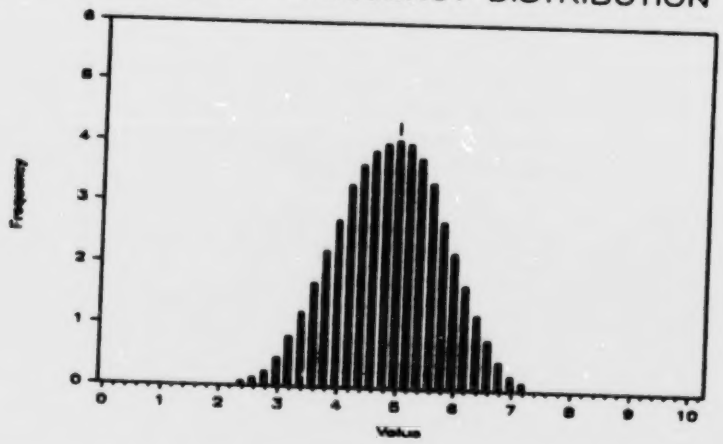


Figure 5b: R—SKEW FREQUENCY DISTRIBUTION

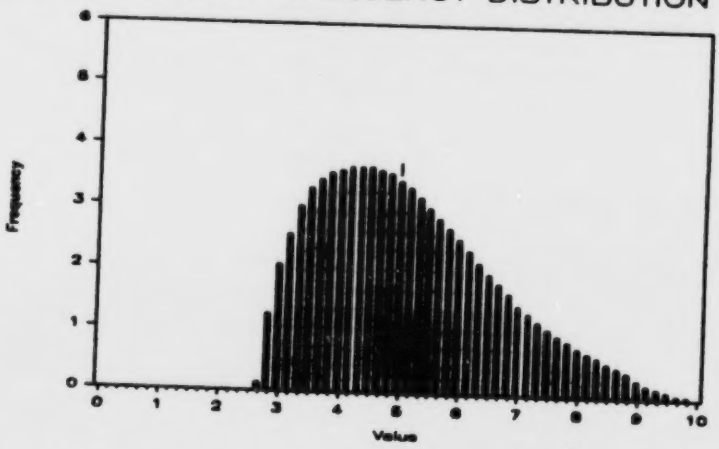
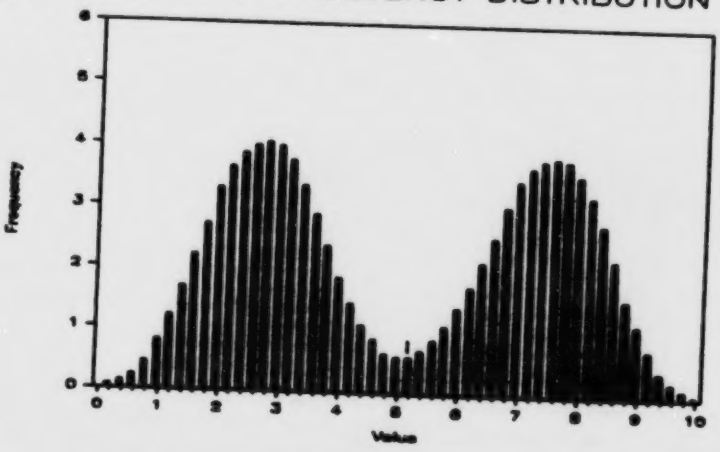


Figure 5c: BIMODAL FREQUENCY DISTRIBUTION



generally indicates that more than one population has been sampled and in classification may indicate the need for the subdivision of a class. Of special note is that the mean value (marked by the |) is one of the least frequently occuring values and may in fact be strongly unrepresentative of the sample population. Even with this kind of distribution non-parametric statistical procedures can be used.

Response Patterns

Knowing the distribution of properties, while uncommon, is still only half of the answer. In order to predict the response of a given unit of land to a given treatment we must know, not only the values of the properties which influence the response but, what the response to each value is. To illustratre the point we will use three hypothetical examples of response to soil water plotted on a sliding banana scale of 0 (severe deficit) to 10 (prolonged inundation) and labelled on the graphs as Drainage. Figure 6a shows a linear response of the proportion of trees blown down by a wind storm as a function of drainage. Blow down did not occur until drainage was restricted enough to limit root distribution. Figure 6b shows a response curve for tomatoes. Yields are very low at values under 2.5 (conditions of deficit), near maximum from 3.0 to 5.5 (no deficit little or no saturation), and low or none beyond 5.5 (significant periods of saturation). This represents a narrow tolerance range to water regime by tomato plants. Clover (Figure 6c) has a much wider tolerance range and shows near optimal response at values ranging from 3.5 to 9.0 indicating that it can grow well under much wetter conditions than tomatoes can.

So What?

The importance of knowing both the distribution of properties and the response curve associated with the properties becomes evident when we superimpose the Tomato response to drainage (Figure 6b) onto a bimodal drainage distribution (Figure 5c) to get Figure 7a. It is important to note that these are two independent curves, the brighter curve representing drainage frequencies and the darker curve representing growth response to drainage. The frequency data has been transformed to a base of 100 so that the numbers shown on the Y-axis correspond to the percentage of the samples having the drainage value shown on the X-axis. In other words 4.0% of the samples had the drainage value 2.8. When looking at the response curve the x-axis is still drainage but the y-axis is read as T/Ha. In other words at a drainage of 4 the growth response is 7.2 T/Ha.

The first point to note is that, at the mean drainage value of 5, tomato response is optimal but very few samples correspond to that value. In fact approximately 50% of the samples have values which lie either below or above the tolerance levels of tomatoes. If we sum the bars for frequencies of values which correspond to productivity ranges 0-1, 1-2, 2-3, 3-4, etc. we can get a frequency distribution of responses for the same data set (Figure 7b). For example the sum of the frequencies of drainage values from 0-1 and 6 to 10, where productivity is less than 1

Figure 6a : SENSITIVITY TO WINDTHROW

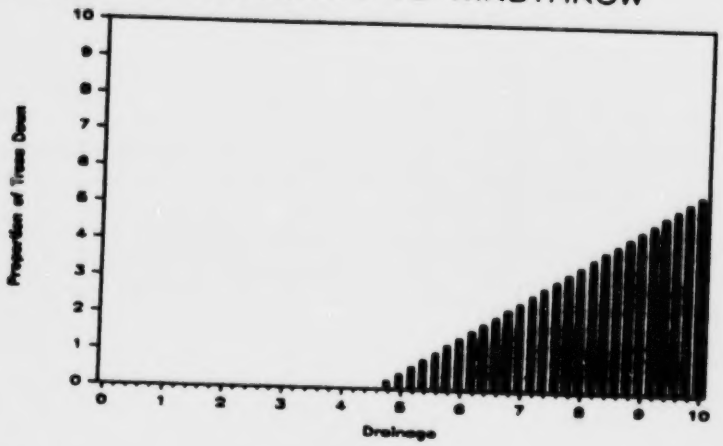


Figure 6b : GROWTH RESPONSE

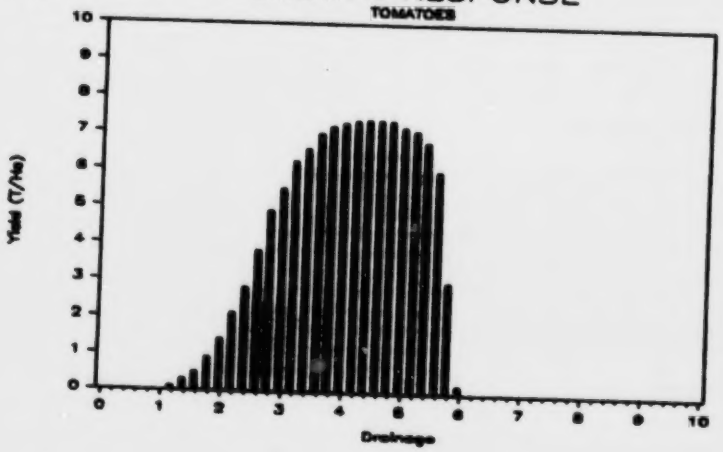
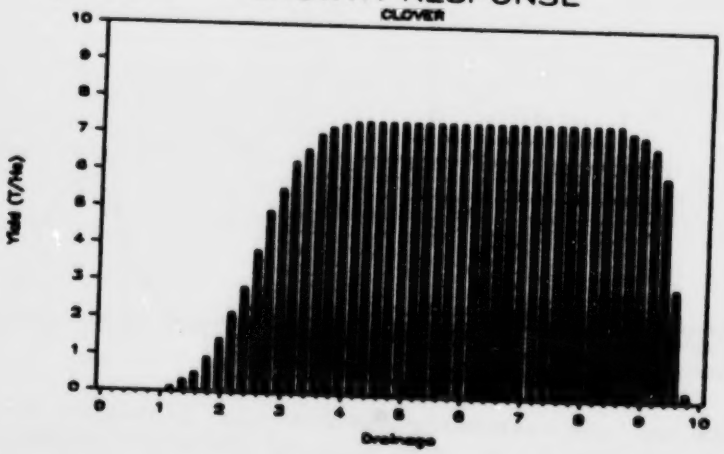


Figure 6c : GROWTH RESPONSE



tonne/ha is approximately 52. This shown as the bar 0.5 T/ha (0.5 is the midpoint of the productivity range 0-1 T/Ha). In other words 52% of the samples have productivity less than 1.0 T/Ha. Similarly less than 10% of the samples have a productivity greater than 7 T/Ha.

By way of contrast, if we superimpose the response to drainage of clover on the same distribution of drainage values (Figure 8a) we find a markedly different result. Here clover produces greater than 7 T/Ha on drainage values between 3.6 and 9.0. The yield distribution for the same productivity ranges as Figure 7b is shown in Figure 8b. The summation of samples where productivity is greater than 7 T/Ha is approximately 58. In other words approximately 58% of the samples will yield clover at greater than 7 T/Ha. This is in marked contrast to 52% of the samples yielding less than 1 T/Ha for tomatoes in Figure 7b. As a final example, if we superimpose the tomato response curve onto a different distribution such as in Figure 9a, we get the yield distribution displayed in Figure 9b. This response pattern is now much more similar to clover on the other distribution.

The final point to be made is that in all three cases, if we simply interpret the mean drainage value and use that to estimate productivity, we will be assuming that 100% of the samples will produce at a level of greater than 7 T/Ha. This will grossly overestimate productivity, in some cases worse than others.

The curves we have been using are largely hypothetical, they were used to demonstrate a point, but Figure 10 shows real plot data in which corn response varies across a single field. The chart of soil distribution shows a total of five possible soils across a transect on which corn heights were measured. If well defined these soil types would give a 5 mode ploymodal distribution if the field were sampled as a single unit.

The most striking difference between the soils corresponds closely with water regime. The Matsqui (MQ) soil having the lowest available soil water storage capacity and the Monroe (M) the next lowest. The Fairfield (F) soil has a higher water storage capacity than Monroe or Matsqui but is imperfectly drained and may show some limitations as a result of high water tables. The Page (PE) and Prest (PR) soils are poorly and very poorly drained respectively and will present problems of excess water to the point where the Prest soil exceeds the tolerance limit of corn. As can be seen there is a strong correlation between productivity and soil map units. Unfortunately on the compound units we can only assume that productivity differences are correlated with soil type because the soil type was not verified at each sample location.

Conclusions

This excercise led us to three conclusions about interpreting soil data:

1) Before we can correctly assess the probable impact or soil management practices we must know; a) the distribution of properties likely to influence our use of the soil and b) the response or

Figure 7a: GROWTH CURVE ON

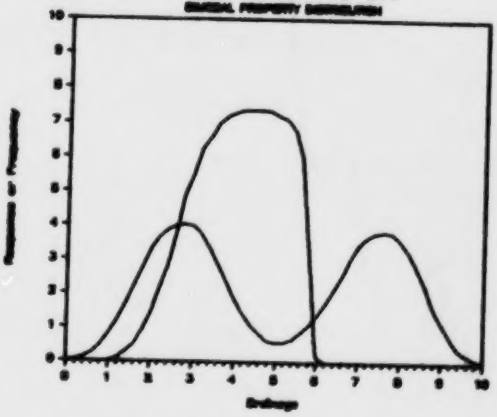


Figure 7b: YIELD DISTRIBUTION 1

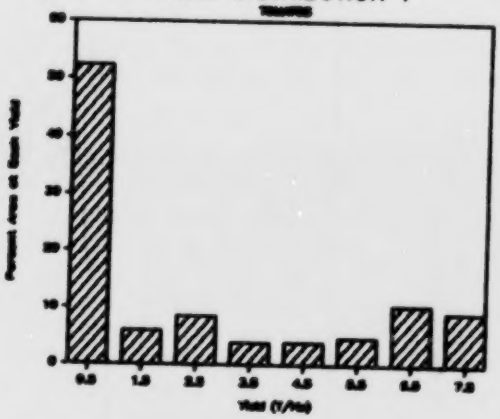


Figure 8a :GROWTH CURVE ON

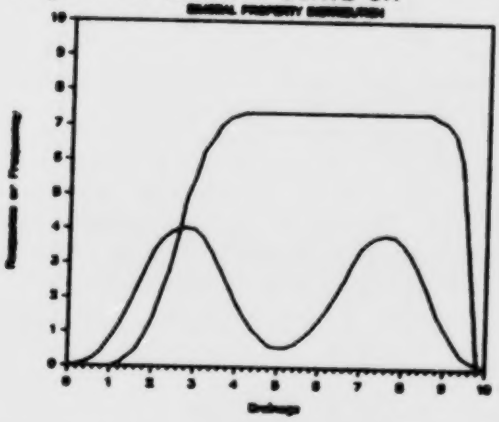


Figure 8b: YIELD DISTRIBUTION 2

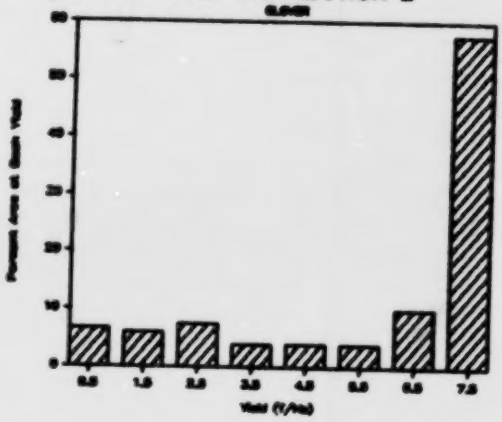


Figure 9a: GROWTH RESPONSE

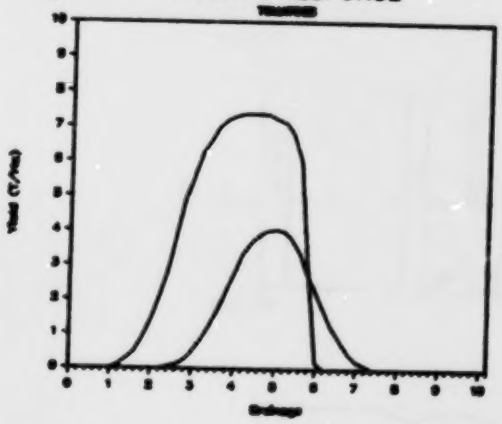


Figure 9b: YIELD DISTRIBUTION 3

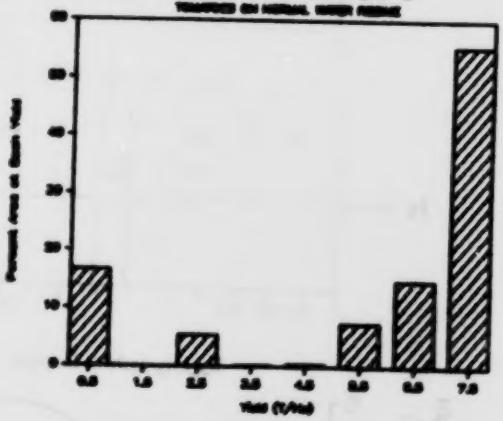
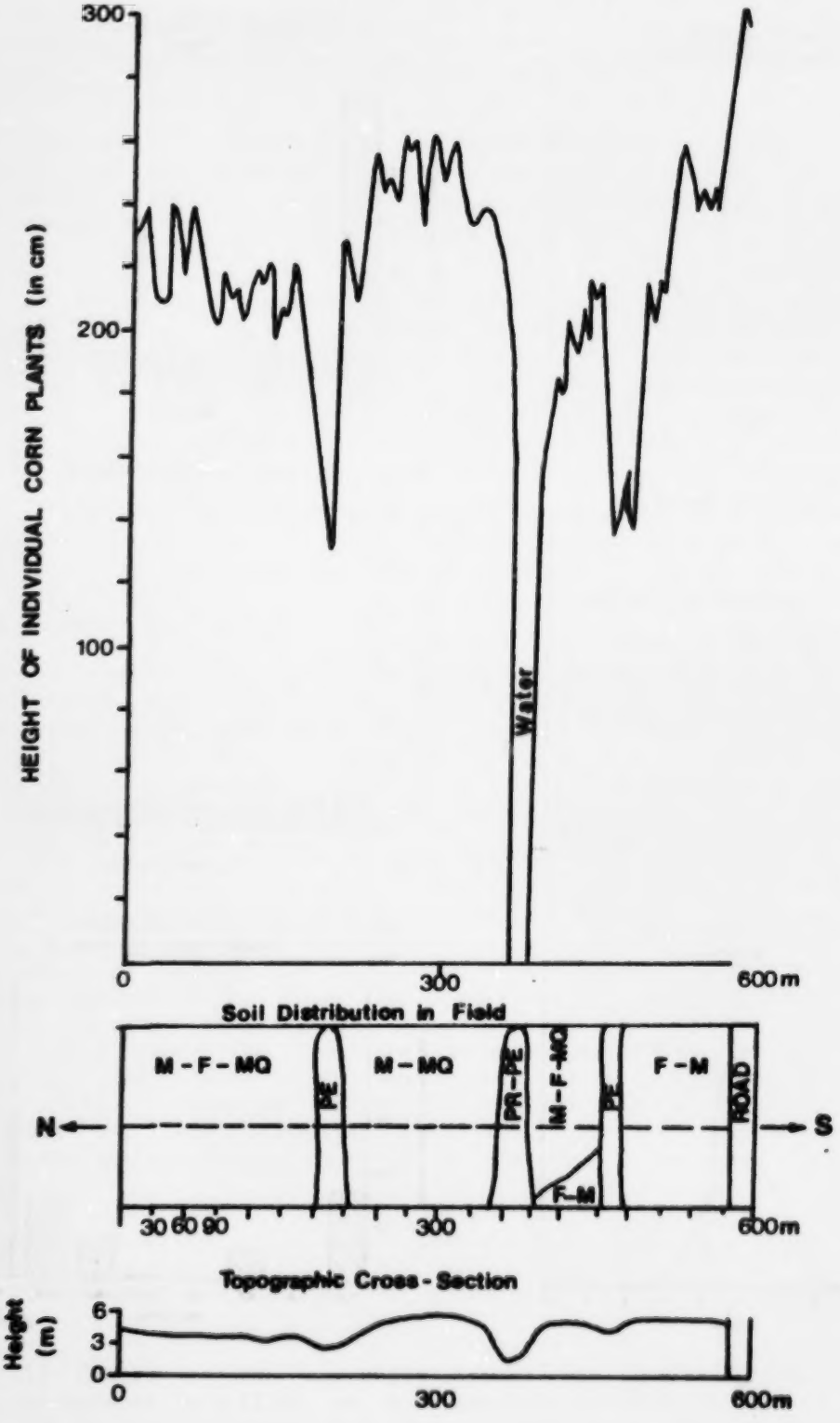


Figure 10 : Corn Growth in Relation to Soil Distribution



influence these values or changes in these values will have on the proposed use,

2) The interpretation of mean values applied to a response curve will in many cases lead to serious under or over estimates of the degree of response, and

3) If we are to use rational models in predicting the response to use of soil properties, we need to have a more effective and statistically sound sampling program. We also need to have more basic research done on the biological and physical responses to soil properties.

There are only a few areas in which our understanding of response is detailed enough to effectively use detailed predictive models. If this is so then what do we do. In those areas where our understanding is adequate we should interpret, not mean values but rather, each sample collected and then determine expected yields or degrees of response for the area as a whole. For those areas where our understanding is inadequate we are left the taxonomic approach of using soil classes and assuming that Soil A will respond in a similar manner where ever it is found. To the extent that the classification properties and their ranges are relevent to the interpretation this approach can be effective. To the extent that they are not relevent it will not be effective. Finally there is the old tried and true method of sock it and see. Try it, if does not work try something else. If it does work do it again or try more to see if it works better. While sounding somewhat unscientific these last two approaches, if directed by our current understanding of system function and properly documented and designed, can provide essential information in the development and testing of the so called rational models.

GEOTECHNICAL SITE INVESTIGATIONS

Agricultural and Forestry developments require a supporting infrastructure which may include access corridors, ports, wharves, and town sites. Construction of these structures and facilities will require building upon or using soil and rock. They will involve cuts and fills, slope stability, bridge and building foundations, culverts, retaining walls, drainage fields, etc.

A geotechnical site investigation is required to obtain the engineering parameters of the subsoils and rocks in order to assess the performance of the structure.

The site investigation may range from and include a regional evaluation of the soil and bedrock geology and hydrogeology, to a detailed site specific investigation carried out with the use of boreholes, test pits and laboratory tests.

The extent and nature of the geotechnical investigation is a function of the size and type of the project and the soils and rocks that are encountered.

The objective of the investigation to identify regional engineering aspects, such as natural hazards (flood plains, debris torrents, avalanches, landslides) to the specific engineering strength and drainage characteristics of the soil and rock required to design the structure.

Before a geotechnical investigation is started, it is essential that all parties involved are fully aware of the type of structure or facility to be built, its required performance and life expectancy.

A geotechnical investigation can only be considered complete when the structure is constructed and performing correctly.

Site investigations, sampling of soils and rocks, and the interpretation and engineering evaluation is not an exact science. Geotechnical engineering requires considerable experience and judgement.

Reference: The Canadian Foundation Engineering Manual, 1985 Edition. Published by the Canadian Geotechnical Society.

John Gadsby, Vancouver.

Present and Future Trends in Soil Fertility Management[1]

J. D. Beaton[2]

Adequate supplies of available plant nutrients are an integral part of high yield crop production systems. The thin profit margins in today's agricultural industry, however, demand close scrutiny of all production inputs including fertilization in order for farmers to survive the current economic squeeze. As a consequence, there is unprecedented interest in ways of improving fertilizer efficiency and in reducing energy and equipment costs.

Information on present and future trends in soil fertility management, especially in the Prairie Provinces, is reviewed in this paper.

I. Fertilizer Placement.

There has been much discussion and research for nearly 20 years on proper placement of plant nutrients (Beaton, 1980). Interest in this subject is largely due to the following developments:

- substantial shift to stubble or continuous cropping which has taken place during the last 20 years in the Prairies, with a resultant increase in N needs.

- damage to seedlings of sensitive crops such as flax, rapeseed, and sunflowers from rates of N and/or P considerably lower than those needed to maximize yields.

- N requirements for small grain crops grown on stubble, and in some cases on fallow, often exceeds the rates deemed safe for seed placement.

- observant farmers reporting higher and more consistent yields when anhydrous ammonia-N was injected into soil in comparison to broadcast applications of granular N sources. Researchers later confirmed these observations.

- search for alternative methods to the traditional seed placement in order to avoid handling large quantities of fertilizer materials during the busy spring and fall seeding periods and to increase the efficiency of fertilizer handling and distributing systems.

---

[1]Ninth British Columbia Soil Science Workshop. Vancouver, B.C., February 21-22, 1985.

[2]Northwest Director, Potash & Phosphate Institute, Box 970, Cochrane, Alta. T0L 0W0

A. Positional Availability

Surface applications of fertilizer nutrients may be ineffective, particularly for spring seeded crops and when precipitation is inadequate to carry them into moist sub-surface soil. This is an important aspect of fertilizer management for P and K and other nutrients with limited mobility. Stranding of mobile N, however, at or near the soil surface can also be a problem since rather large amounts of this nutrient must be present in the root zone for satisfactory crop growth. Broadcast applications of N are effective when there is sufficient moisture in the fall, winter, or within about three weeks after crop emergence to move added N sufficiently deep into the root zone. In areas of high precipitation such as in coastal B.C. attention must be given to prevent N leaching. The problem of positional unavailability is most serious in dry years and/or in regions of low precipitation.

It should also be noted that there can be ammonia volatilization losses from ammoniacal forms of N fertilizer left unincorporated on the soil surface. Such losses are influenced by several factors including soil pH, temperature, cation exchange capacity, soil texture, and soil moisture.

Many experiments in Idaho, Kansas, Montana, Nebraska, North Dakota, and Oklahoma have shown the superiority of deep placed applications of N and P when compared to surface broadcast and incorporated applications of these two nutrients or other methods of application which separated most of the applied N from the P (Murphy, 1983). Similar results have been reported in the Prairie Provinces (Harapiak et al., 1982; Harapiak & Flore, 1984).

Extensive research in the Prairies summarized by Harapiak and Flore (1984) indicates that pre-plant deep banding can be a more effective method of applying N fertilizer for cereal crops, particularly under conditions of growing season moisture stress. They noted that the traditional practice of applying P directly with the seed has not consistently proved to be the most effective method of application. Placement of P in a common band with N was usually more effective in the lower rainfall regions while the conventional seed row application of P was generally best in the higher rainfall regions or under irrigation. It is possible that the salt effect (physiological drought) from added fertilizer P was detrimental under the drier conditions.

Harapiak and Flore (1984) also concluded that yields under favourable moisture conditions were maximized by splitting the required P between the pre-plant deep band and the seedrow. The relative effectiveness of fertilizer placement methods was

also found to be influenced by soil zones, soil moisture conditions, and soil test levels.

Plant uptake of nutrients from pre-plant deep bands can be impaired if seeding is done too soon after fertilization. Phosphate recovery was restricted when ammoniacal sources of N at rates of 90 lb. of N/A were deep banded at 12" spacing near the time of seeding. High rates of K in common N-P bands similarly interfered with P uptake. This availability problem can be largely avoided by delaying seeding for about three weeks after deep banding fertilizer. Deep banding in the fall will, of course, eliminate this problem for spring seeded crops.

B. Immobilization by Crop Residues

There is a slow but definite trend toward less tillage in the grain producing areas of western Canada (Ukrainetz, 1984). Thus, crops are being planted into fields with relatively large amounts of crop residue on or near the soil surface. Microbial decomposition of these surface organic residues can result in immobilization of mineral nutrients, particularly nitrogen, resulting in early spring or season-long deficiencies for crops.

Cereal straws are frequently low in N, P, and S and the micro-organisms decomposing them will compete with crops for supplies of these and other essential nutrients. There will likely be little microbial immobilization of N when the straw residues contain more than about 1.25 to 1.50 percent N.

The depressive action that surface accumulations of straw can have on the effectiveness of surface applied urea N for production of barley grain and straw is illustrated in Table 1. Banding urea at a depth of 10cm greatly improved its performance and reduced N immobilization. Very large urea particles, many times heavier than conventional granules, was another successful way of minimizing N tie-up in straw residue (Nyborg & Malhi, 1982).

C. Benefits of Starter Fertilizer

Root development and activity are restricted by low temperatures and the diffusion of nutrients such as P and K to plant roots is also reduced by low soil temperatures. It is well known that starter applications of P and K are particularly effective at low soil temperatures and often produce large yield increases even when the soil test levels for these nutrients are medium to high (Murphy, 1983). The chances of P,K, and N and S starter fertilizers producing beneficial effects are high under no-till and reduced tillage systems because of the prevailing lower early growing season temperatures.

The possibility of starter fertilizer X plant disease interactions also exists. Pythium root rot infections causing yield losses of 750 to 1000 kg/ha have been reported by Cook and Haglund (1982) to occur in the majority of late-sown and annual cropped winter wheat fields, particularly those under minimum and no-till. Although the effects of this disease can be greatly reduced by fumigation and by either seed or soil treatments of the fungicide Ridomil or Apron, it is possible that starter P may also help in its control. Phosphorus placed with seed of hard red spring wheat was a major factor in the virtual elimination of browning root rot caused by Pythium spp. (Vanterpool, 1962). Common root rot (Cochliobolus sativus) attack on spring wheat has been suppressed by drilling P with the seed (Verma et al., 1975).

D. Weed Competition

Some weeds such as green foxtail (wild millet) germinate very close to the soil surface at depths of 1 to 2.5 cm and compete aggressively for and respond to N fertilizers (Maurice & Morrison, 1980). Seed production by green foxtail improves with increased additions of N, increasing the chances for heavy infestations the following year. The impact of increasing densities of green foxtail on wheat yields is shown in Figure 1.

Because of green foxtail's ability to use N efficiently, restricting its access to this nutrient is an important consideration in its control strategy. Nitrogen placed in a deep band or injected as anhydrous ammonia will be preferentially located for the benefit of the crop.

E. Denitrification

Under conventional tillage in the northern parts of the Prairie Provinces, fall applied N fertilizers are often less effective than when the same sources are spring applied. Denitrification has been identified as the principal mechanism of overwinter loss of N in cultivated Alberta soils (Heaney et al., 1984). Black Chernozemic and Gray Luvisolic soils appear to be more susceptible to spring denitrification processes than the drier Brown and Dark Brown Chernozemic soils.

The efficiency of fall applied ammoniacal forms of N in the Prairies can be greatly improved by simply delaying application to late October or early November (Figures 2 and 3). Late fall deep banded ammoniacal fertilizer N can approach or equal the effectiveness of spring-banded N.

Denitrification losses of N can also be substantially suppressed by placing ammoniacal N sources in narrow, concentrated bands at depths of 4 to 5 inches (10 to 13 cm) and spacings of 12 to 18 inches (30 to 46 cm). A narrow spacing of 12 inches is usually recommended.

Placement of large urea particles, weighing up to 1 or 2g, or concentrating regular sized urea granules in"nests" of approximately 2.5 g at spacings of about 18 x 18 inches (46 x 46 cm) apart will also greatly improve the performance of fall applied N in situations where denitrification is a serious problem (Malhi et al., 1984). Both the large granules and "nests" are placed at depths of 2 to 2.5 inches (5 to 6 cm) in the soil. Table 2 clearly shows the benefit of "nesting" for production of barley grain.

Nitrification inhibitors such as carbon disulphide and trithiocarbonate have also improved crop response to fall-applied N in areas where denitrification reduces the effectiveness of fertilizer N (Malhi & Nyborg, 1982). Studies have been conducted with nitrification inhibitors in British Columbia (Guthrie & Bomke, 1981), mainly for the control of N leaching losses.

F. Nutrient Interactions in Sub-Surface Bands.

Placement of N, especially ammoniacal forms, and P in a common band has been found to increase P fertilizer efficiency and crop yields. Enhanced root development and activity, metabolic effects of N nutrition on P absorption and translocation, and favorable effects on P solubility are several of the main explanations for this beneficial interaction.

Results of recent studies at Colorado State University (Hanson & Westfall, 1983; Westfall & Hanson, 1984) suggest the following causes for the greater effectiveness of P in the presence of NH_4-N:

(i) the initial high pH immediately after application allows formation of sparingly soluble but nevertheless highly available Ca-P reaction products such as dicalcium phosphate and octacalcium phosphate (Figure 4).

(ii) then the production of H^+ during nitrification increases P solubility as phosphate potential moves upwards on the calcium phosphate isotherms towards those of Fe-P and Al-P

(iii) this rapidly decreasing pH allows the soluble P reaction products to persist resulting in higher P availability for longer periods.

Retardation of nitrification by an inhibitor such as nitrapyrin prolonged the existence of these more soluble P compounds. It was also observed that soil pH was higher with NO_3-N plus P dual treatments than it was when NH_4-N was added in combination with P (Table 3). This is likely due to uneven anion and cation release and uptake by plants.

II. Soil Building - Phosphorus

After much controversy and hesitancy it is now recognized that heavy rates of fertilizer P on Chernozemic soils will be available to crops in succeeding years. Long-term field experiments conducted on calcium-dominated soils in Alberta, Saskatchewan, Manitoba, Idaho, Montana, North and South Dakota, Oregon, and New Mexico have proven that large batch applications of from about 80 to 90 to 250 lb. of P_2O_5/A can remain effective for periods of 8 to 10 years or longer (Tisdale et al., 1985). Advantages of such applications are: (i) time saving in the spring resulting in more efficient use of time during the busy spring seeding period, (ii) avoidance of fertilizer salt damage at the rates needed to maximize yields of sensitive crops like flax and canola, (iii) raise available soil P to satisfactory levels for crops with high P requirements such as rapeseed/canola, alfalfa, potatoes, etc. (iv) through the long-term effects of plant biocycling and/or tillage, distribute P more uniformly throughout the root zone thereby encouraging maximum P uptake, even in drought years, and (v) economic incentives including discounts for fall fertilizer purchases, year-end income tax deductions, and hedging against escalating fertilizer costs.

High levels of residual P are desirable because they assure that available soil P levels are adequate to satisfy crop requirements over a wide range of climatic and cropping conditions. It should be noted, however, that when P soil building is practised soil and plant tissue Zn levels should be monitored, particularly for sensitive crops like beans, corn, and flax. Wagar and Stewart (1984) observed that large residual P applications significantly depressed Zn uptake by hard red spring wheat. Foliar applications of 0.3 kg of Zn/ha of zinc chelate consistently increased yields for all residual P treatments.

Some of the results obtained in the first five years of a long-term residual P study at the University of Saskatchewan are given in Table 4. The highest overall yields occurred with the combination of 184 kg of P_2O_5/ha plus 46 kg of P_2O_5/ha annually with the seed. Two other very effective treatments involving the addition of much less P were (i) a batch treatment of 92 kg of P_2O_5/ha combined with 23 kg of P_2O_5/ha annual seed placement and (ii) 184 kg of P_2O_5/ha plus 5.75 kg of P_2O_5/ha annually with the seed.

Net returns from several of the various methods of P application are compared in Table 5. Potential increases in earnings were greatest with the combination of 92 kg of P_2O_5/ha initially plus 23 kg of P_2O_5/ha annually with the seed (82 lb. of P_2O_5/acre plus 20.5 lb. of P_2O_5/acre annually). The next most profitable treatment was a single application of 184 kg. of P_2O_5/ha plus 5.75 kg of P_2O_5/ha applied yearly with the seed (164 lb. of P_2O_5/acre plus 5 lb. of P_2O_5/acre). Jose and Nilsen (1982) in their analysis of results of heavy batch

applications of P at two sites each in Manitoba and Saskatchewan concluded that there is a potentially economic advantage for such P additions in the higher rainfall areas of the Prairies where wheat can be grown continuously or with limited summer-fallowing.

The findings of Halvorson and Black (1984) in a long-term residual P study established in 1967 and 1968 at Sidney, Montana are in close agreement with the western Canadian results. Averaging data from 21 crops, single P applications of 22, 45, 90 and 180 kg of P/ha increased yearly grain yields 6,11,15 and 19 percent without N, and 10,20,32 and 37 percent with 45 kg of N/ha, respectively, above that of the no P treatment.

Robertson of the University of Alberta and Penney of Ablerta Agriculture are now investigating the residual effects of K for barley production. Treatments of 300,600 and 900 kg. of K_2O/ha were made in the spring of 1982. Annual applications of 0,30 and 60 kg of K_2O/ha were superimposed on the residual additions. Although beneficial effects of the residual K on barley yields have been observed, a large portion of the added K could not be recovered by ammonium acetate extraction. Results of this Alberta work have not to date been published.

II Fertilizer Application Systems - Present

Only relatively new fertilizer application equipment will be discussed briefly in this section.

A. Deep Banding Applicators.

1. Anhydrous Ammonia. Injection of this well-known N source is a form of deep banding which has had a long history of use. A number of modifications have been made to anhydrous ammonia application equipment to increase versatility and to avoid all or most of the usual pre-application tillage. These include the following:

(i) heavy duty spring shank and a narrow knife opener 0.5 to 0.75 inches (1 to 2 cm) wide to permit deeper penetration in untilled soils.

(ii) convertors for reducing NH_3 pressure to near atmospheric allowing only about 15 percent of the NH_3 to vaporize and the remaining 85 percent exists as a liquid. The need for deep injection and pre-application tillage is reduced. One large convertor may be used for each applicator rig or small mini-convertors may be attached to each shank.

(iii) pneumatic delivery systems for the simultaneous application of dry granular fertilizer materials. Anhydrous ammonia and the dry fertilizers flow through separate tubes

down the back of the knife or other devices used to penetrate the soil.

(iv) systems for applying fluid fertilizers, normally clear liquids, for the simultaneous application with anhydrous ammonia. As is the case for the dry pneumatic systems, the anhydrous ammonia and liquid fertilizer materials are fed down separate lines attached to the back of the injection tool.

2. Deep Banding During Tillage. The chisel plow or field cultivator may be used as a base for either (i) pneumatic application of dry fertilizer materials (ii) clear liquid or suspension fertilizer application, and/or (iii) injection of anhydrous ammonia, especially in conjunction with the use of a convertor.

Cultivator-air seeder units can be used for either deep placement of fertilizer before seeding, seeding, or applying fertilizer at seeding time. Many of the popular units do not place dry fertilizer in a narrow or tight band. However, changes can be made so that fertilizer will be confined more or less to a definite band.

3. One-Pass Seeding and Fertilization. Although placement of some fertilizer in the seed row is not new, provision of the total fertilizer requirement with seeding equipment is novel. For example, the Yielder Pioneer Drill developed primarily for no-till cropping systems, has the capability of simultaneously placing fertilizer with the seed and deep banding fertilizer between the rows. A major disadvantage of one-pass seeding and deep fertilizer injection with double-disk openers is that very heavy drills, as heavy as 1,500 lb/ft of drill width, are required to penetrate hard soils. Also, these drills are expensive.

The double-disk openers in the Yielder drill cause considerable soil disturbance and weed emergence and growth can be stimulated in the fertilizer opener slots. This problem can be largely overcome by seeding pairs of closely spaced rows ("paired rows") with wider spacings between"paired" rows and deep injecting fertilizer only between the"paired" seed rows. Dry fertilizer products are placed with the seed while there are options of deep banding dry fertilizer materials, anhydrous ammonia, or fluid sources at depths to 7.5 inches.

There are other recently developed no-till drills that place fertilizer with the seed and either band fertilizer below the seed or to the side of the row. Others band fertilizer with the seed and broadcast fertilizer between the disc openers.

III. Fertilizer Application Systems - Future

The first of two innovative application systems providing some insight into fertilizer application equipment of the future is

the Chinook system which has the progressive feature of on-the-go seed and fertilizer rate adjustments (Anon., 1984). A microcomputer mounted in the tractor cab and operated by the driver activates a series of switches to provide infinite adjustments to the metering units. With this system fertilizer rates can be changed according to the tractor operator's interpretation of soil properties, slope position, etc.

In the future, such application equipment could become even more advanced using instruments to monitor important soil differences and automatically make the appropriate adjustments in rates and kind of fertilizer application. Also, foreseen is the possibility of the entire fertilizer spreading operation being computer programmed and the equipment guided by electronic navigational aids.

Nutri-Blast 2000 is a new concept for clear liquid fertilizer application (Clapp, 1984). It is a high pressure applicator that injects clear liquid fertilizer into the soil without the aid of knives, coulters or other tillage implements. The fertilizer solutions under pressures of 100,000 + psi cut through crop residues and are injected into soil to depths of two to three inches. Although high pressures of 2000 psi were first deemed necessary, there are indications that lower pressures of about 800 psi may be satisfactory. Nutri-Blast equipment is expected to be manufactured by the John Blue Company, Huntsville, Alabama and be commercially available in 1985.

The improved effectiveness of ammoniacal N sources placed in sub-surface "nests" was mentioned previously. Several groups of agricultural engineers are attempting to develop pneumatic nesting fertilizer applicators.

REFERENCES

Anonymous. 1984. Change fertilizer rates on-the-go. Grainews Sept. 14th, 1984. p.1,23.

Beaton, J.D. 1980. The role of NPKS. p. 323-445. In Soils and land resources. Prairie Production Symp. Canadian Wheat Board Advisory Committee, Saskatoon, Saskatchewan. October 29-31, 1980. Canadian Wheat Board, Winnipeg,

Clapp, J.G. Jr. 1984. Nutri-blast 2000 - A new concept for clear liquid fertilizer application. p.34-35. In Opportunities '84 Proceedings Book, National Fertilizer Solution Association. July 25-27, 1984.

Cook, R.J., and W.A. Haglund. 1982. Pythium root rot, a barrier to yield of Northwest wheat. Wash. Agric. Exp. Sta. Res. Bull. XB0913. Pullman, WA.

Guthrie, T.F., and A.A. Bomke. 1981. Effects of low temperature and nitrification inhibitors on urea hydrolysis. Can. J.Soil Sci. 61: 529-532.

Halvorson, A.D., and A.L. Black. 1984. Long-term residual P effects on crop yields and P uptake. Agron. Abstr. American Society of Agronomy, Madison, WI. p. 206.

Hanson, R.L., and D.G. Westfall. 1983. Phosphorus solubility relationships of common N and P fertilizer injection zones. p.50-52. In Abstracts of Papers Presented at the Western Phosphate Conference, Fort Collins,CO, March 17-18, 1983. Phosphate Work Group, Western Soil and Water Research Committee.

Harapiak, J.T., N.A. Flore, and J.G. Timmermans. 1982. Deep banding of N-P fertilizers: Some conclusions and recommendations. p.94-108. In Proc. of the 1982 Soils and Crops Workshop, Saskatchewan Advisory Council on Soils and Agronomy and University of Saskatchewan, Saskatoon, Sask. February 18-19, 1982. Division of Extension and Community Relations Publication No. 464. University of Saskatchewan, Saskatoon, Sask.

Harapiak, J.T., and N.A. Flore. 1984. Pre-plant banding of N and N-P fertilizers: Western Canadian research. In Proc. Thirty-Fifth Northwest Fertilizer Conference. July 17-18, 1984. Pasco, WA.

Harapiak, J.T., and D.C. Penney. 1984. Efficient use of nitrogen-----the N and P interaction. p.102-114c. In 21st Ann. Alberta Soil Science Workshop Proceedings. February 21-22, 1984. Faculty of Extension, University of Alberta, Edmonton, Alta.

Heaney, D.J., A.T. Blades, S.S. Malhi, and M. Nyborg. 1984. Changes in crop available nitrogen in soils in winter: Mineralization, immobilization, and dentrification. p.46 59.In 21st Ann.Alberta Soil Science Workshop Proceedings. February 21-22, 1984. Faculty of Extension, University of Alberta, Edmonton, Alta.

Jose, H.D., and L. Nilsen. 1982. Batch and annual phosphorus fertilizer application for wheat in western Canada. Better Crops 66: 29-31. Summer 1982.

Malhi, S.S., and M. Nyborg. 1982. An evaluation of carbon disulphide as a sulphur fertilizer and as a nitrification inhibitor. Plant Soil 65: 203-218.

Malhi, S.S., M. Nyborg, J.T. Harapiak, and D.C. Penney. 1984. Efficiency of fall-applied nitrogen as influenced by method of placement and date of fall application. p. 75-101. In 21st Ann. Alberta Soil Science Workshop Proceedings. February 21-22, 1984,. Faculty of Extension, University of Alberta, Edmonton, Alta.

Maurice, D.C., and I.N. Morrison. 1980. Green foxtail: Manitoba's most abundant weed. Weed Facts. Agdex 642. Manitoba Agriculture, Winnipeg, Man.

Murphy, L.S. 1983. Fertilizer application techniques--what lies ahead? p.24-49. In Abstracts of Papers Presented at the Western Phosphate Conference, Fort Collins, CO. 17-18 March 1983. Phosphate Work Group, Western Soil and Water Research Committee.

Nyborg, M., and S.S. Malhi. 1982. A summary of placement and fall versus spring application of nitrogen fertilizers. p.119-135. In Proc. of the 1982 Soils and Crops Workshop, Saskatchewan Advisory Council on Soils and Agronomy and University of Saskatchewan, Saskatoon, Sask. February 18-19, 1982. Division of Extension and Community Relations Publication No. 464. University of Saskatchewan, Saskatoon, Sask.

Tisdale, S.L., W.L.Nelson, and J.D. Beaton. 1985. Soil Fertility and Fertilizers 4th edition. Macmillan Publishing Company, New York, N.Y.

Tomar, J.S., and R.J. Soper. 1981. Fate of tagged urea N in the field with different methods of N and organic matter placement. Agron. J. 73: 991-995.

Ukrainetz, H. 1984. Fertilizer placement for maximum effectiveness. p.209-234. In "The Optimum Tillage Challenge". 2nd edition. Proc. of the Saskatchewan Institute of Agrologists Update Series. November 6-8, 1984. University of Saskatchewan Printing Service, Saskatoon, Sask.

Vanterpool, T.C. 1962. Pythium root rot of wheat in Saskatchewan. Can. Plant Dis. Survey 42(4): 214-215.

Verma, P.R., R.D. Tinline, and R.A.A. Morrall. 1975. The epidemiology of common root rot in wheat. II. Effects of treatments, particularly phosphate fertilizer, on incidence and intensity of disease. Can. J. Bot. 53:1230-1238.

Wagar, B.I., and J.W. B. Stewart. 1984. Maximum yields of spring wheat and P fertilization practices. Maximum Wheat Yield Systems Workshop. March 7-9, 1984. Denver, Co. Potash & Phosphate Institute and Foundation for Agronomic Research.

Westfall, D.G., and R.L. Hanson. 1984. Reaction products of dual application of N and P fertilizers. Agron. Abstr. American Society of Agronomy, Madison, Wi. P.271.

Table 1. Comparisons of grain yield and straw yield as affected by organic matter and N applications. (Tomar & Soper, 1981).

Straw placement	Nitrogen placement: Surface broadcast	Banded at 10 cm depth	No N
	kg/ha		
	Grain		
Mixed in soil to 10 cm depth	2,612 bc*	3,007 cd	1,659 a
Spread on soil surface	3,218 cde	4,322 f	1,535 a
No straw	3,629 def	3,965 ef	2,128 ab
	Straw		
Mixed in soil to 10 cm depth	3,636 bc	4,243 cd	2,325 a
Spread on soil surface	4,579 de	5,568 f	2,340 a
No straw	4,916 def	5,108 ef	2,849 ab

*Means followed by the same letter for each component do not differ significantly at p=0.05 by Duncan's New Multiple Range Test.

Table 2. Effect of urea placement method in fall and spring on grain yield and uptake of N in grain + straw of barley (50 lb. N/ac. 20 field experiments, Alberta). (Malhi et al., 1984).

Treatment	Grain yield (bu/ac)	% of applied N recovered in grain + straw
Control	29.5	
Urea mixed - fall	45.0	26
Urea banded - fall	50.7	38
Urea nest - fall	57.0	52
Urea mixed - spring	61.3	64

Table 3. Effect of fertilizer treatment and time after application on $NaHCO_3$ extractable P in the fertilizer band (Hanson & Westfall, 1983).

Treatment	Days after Application			
	1	15	30	60
10-34-0 alone	58	84	69	81
NO_3^- plus 10-34-0	96	91	99	116
NH_4^+ plus 10-34-0	103	109	96	102
NH_4^+ + nitrapyrin plus 10-34-0	107	106	104	101
$LSD_{.10}$	27	14	22	NS

Table 4. Modes of P application producing maximum and near maximum yields of wheat at the Kernen Farm, University of Saskatchewan (Wagar & Stewart, 1984).

Phosphorus treatment (kg P_2O_5/ha)		Average grain yield 1979-1983		Total P applied
Residual	Seed placed yearly	kg/ha	(bu/a)	kg P_2O_5/ha
184	46	2766	(41.0)	414
92	23	2718	(40.3)	207
46	46	2675	(39.7)	276
184	5.75	2673	(39.7)	213
368	0	2614	(38.8)	368
184	0	2552	(37.9)	184
0	46	2512	(37.3)	230
0	0	1943	(28.8)	0

Table 5. Comparison of net returns from the modes of P application producing maximum and near maximum yields of wheat at the Kernen Farm, University of Saskatchewan (Wagar & Stewart, 1984)

Phosphorus treatment (lb P_2O_5/A)			Average yearly net returns over and above fertilizer and harvesting costs (1979-1983) * $/A
Residual	Seed placed yearly	Total	
164	41	369	22.27
82	20.5	184	30.82
41	41	246	24.92
164	5	190	28.28
328	0	328	16.72
164	0	164	23.28
0	41	205	18.64
0	0	0	-

* Wheat at $4.00/bu, P_2O_5 at 30¢/lb, and harvesting cost at 30¢/bu.

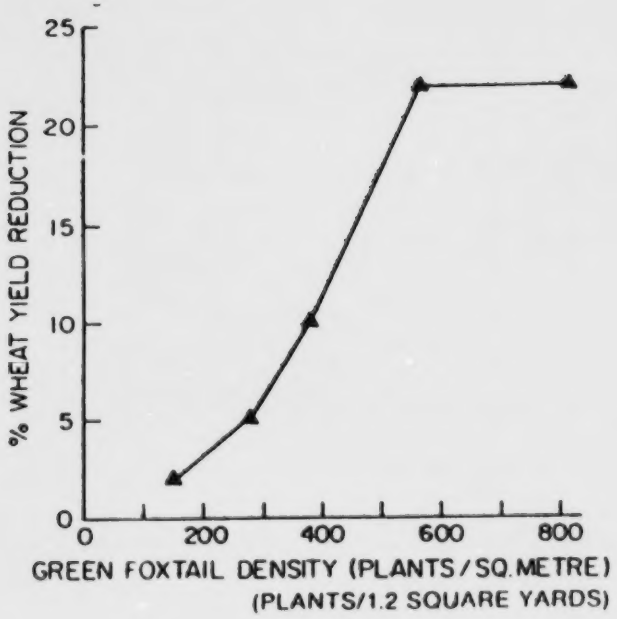


Figure 1. Reduction in wheat yields caused by increasing densities of green foxtail (Maurice & Morrison, 1980).

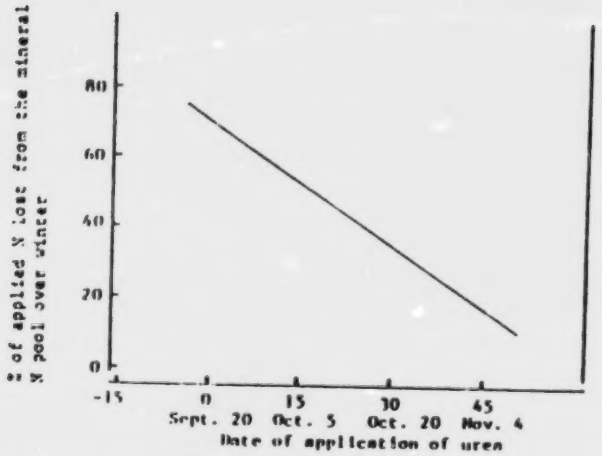


Figure 2. Effect of date of application in fall on the overwinter mineral N losses from fall-applied urea N at 50 lb N/ac (Malhi et al., 1984).

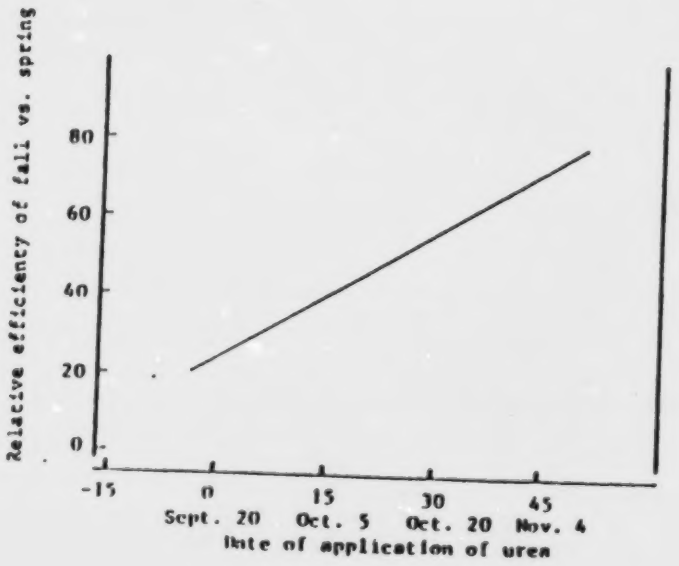


Figure 3. Effect of date of fall application on the relative efficiency of fall vs. spring-applied urea at 50 lb N/ac in increasing grain yield of barley (Malhi et al., 1984).

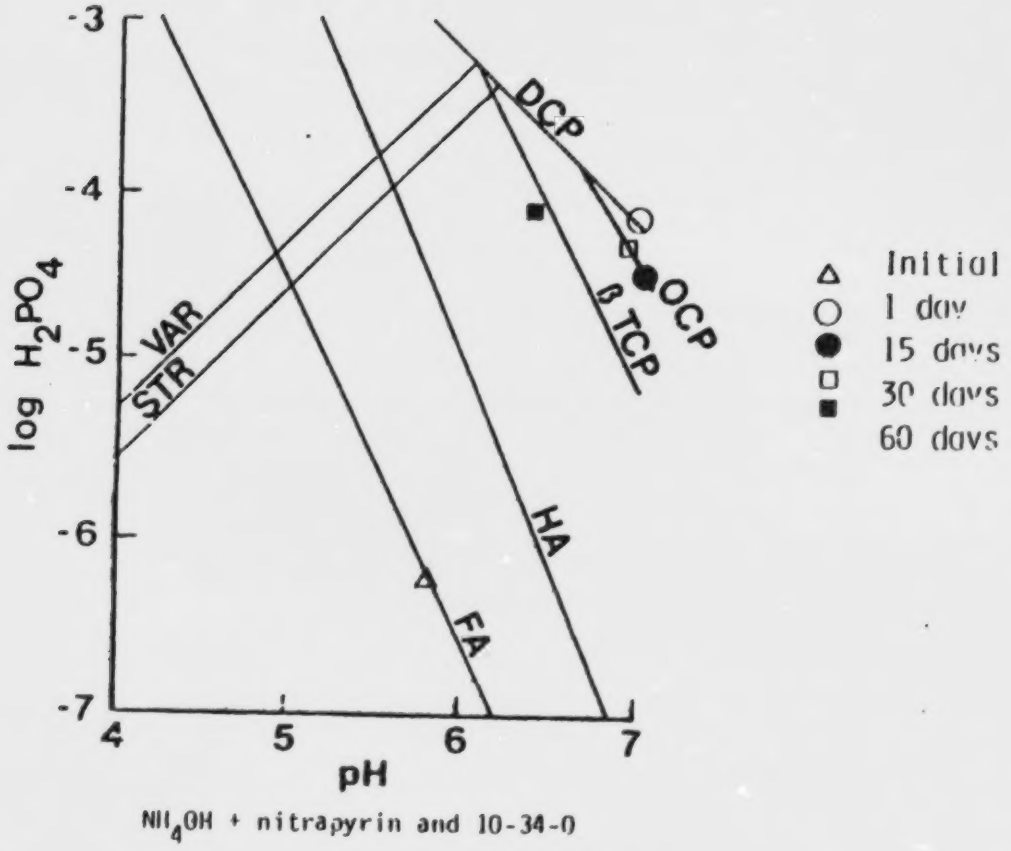


Figure 4. Changes in P solubility in the injection zone with time after application of NH_4OH + nitrapyrin plus 10-34-0 (Hanson & Westfall, 1983).

IMPLICATIONS OF SOIL VARIABILITY ON FERTILIZER ASSESSMENTS FOR CROP PRODUCTION

C. Grant Kowalenko
Agriculture Canada, Research Station,
Agassiz, B.C.

I am going to approach this topic with an end user in mind. The end user will be fairly specific, that being a farmer. Some of my comments will, therefore, not be directly applicable to other end users such as foresters and environmentalists. However, the basic principles should have more general applicability.

To deal with this topic I will outline general areas which contribute to variability and make comments on the implications of each to fertilizer assessments for agricultural crop production.

I. THE SOIL SAMPLE

A. Factors affecting variability

(1) Natural
- (a) deposition/genetic
- (b) physical features (slope, elevation, etc.)
- (c) spacial (three dimensional)
- (d) nutrient (mobility/reactivity, response to redox conditions, etc.)

(2) Management of:
- (a) landscape (levelling, drainage, etc.)
- (b) field (division and use arrangement of a parcel of land, etc.)
- (c) soil (cultivation, etc.)
- (d) amendments (manure, lime, fertilizer; banding, broadcasting...)
- (e) cropping (selection and distribution of crop, harvesting, spraying, etc.)

(3) Sampling procedures
- (a) area specifications (field size, number per field, etc.)
- (b) distribution (spot, random, grid, etc.)
- (c) depth
- (d) timing (spring, fall, etc.)
- (e) method (shovel, core, etc.)

B. Implications to the user

In order for a single soil sample to accurately (i.e.) realistically represent a field, the problem can be addressed from two perspectives. The first is to manage the unit area to be sampled to achieve maximum uniformity. Influencing the effect of the natural factors is not impossible but often impractical. Management is an on-going activity which is often forgotten in the rush or that is not considered with respect to the uniformity of taking a soil sample.

The other part of getting a representative soil sample is the sampling procedure. If management practices such as spot applications of fertilizer or manure result in less uniformity, sampling procedures would have to be

adjusted accordingly. Gary Bank (M.Sc. thesis at U.B.C. in 1984) has provided some data on variability of Fraser Valley soils.

II SAMPLE HANDLING

A. Factors affecting variability
(1) Preparation (drying, grinding, stone removal, etc.)

(2) Storage (temperature, moisture content, etc.)

(3) Contamination
(a) solid (fertilizer, metals from grinders, etc.)
(b) liquid
(c) gaseous (NH_3, H_2S, SO_2, etc.)
(d) biological

B. Implications to the user

The user does have a great deal of control over this operation. In most cases where this has not been done properly, it has been done carelessly out of ignorance. By understanding why things are done in a particular way, more care would be taken because the user has a vital interest. Different handling methods are important for different nutrients.

III LABORATORY ANALYSES

A. Factors affecting variability (chemical analyses considered only)
(1) Extraction/digestion
(a) Type of extractant
(b) Concentration of extractant
(c) Ratio of extractant to sample
(d) Temperature
(e) Time

(2) Determination
(a) form (speciation)
(b) interference
(c) detection range

(3) Contamination

B. Implications to the user

The user largely looses control over variability at this stage if he does not do the analyses himself. Presently, British Columbia users have a selection of analytical laboratories from which they can choose. Competition among laboratories hopefully encourages quality of operations. The user can select on the basis of the quality of the analyses and/or on the basis of the type of analysis (especially with respect to the type of extractant). Independent quality assessment programs and publication of methods would greatly help. From the perspective of the farmer being the user, the biggest problem is education. From my observations, soil testing is vaguely understood and even misunderstood.

IV. DATA INTERPRETATION

A. Factors affecting variability

(1) Soil test correlation

Climate, soil and crop factors are involved in the soil test correlation. Each of these factors varies as a continuum rather than as distinct units plus they interact in an almost infinite variety of ways. This means that the soil test correlation includes:

(a) approximations
(b) generalizations
(c) extrapolations

(2) Range of nutrients interacting

(a) Law of minimum
(b) Synergistic and antagonistic

(3) Philosophies

eg (a) Sufficiency level
(b) Maintenance level (soil conservation)
(c) Balance (cation ratio, P/Zn)

(4) Concerns

(a) Short term/individual (i.e.) economics (quality and quantity)
(b) Long term/individual (i.e.) agronomic/conservation
(c) Short and long term/corporate (i.e.) environmental

B. Implications to the user

Again, as with laboratory analyses, the user largely looses control over variability due to data interpretation because traditionally this has been done for him. Currently, the farmers tend to control the variability in interpretations by adjusting to suit their philosophy and concerns behind the interpretation.

The user, in my opinion, has not considered the variability involved in the soil test correlation. The soil test value is usually reported as a single, unique number and is often associated to mean a precise value. In actual fact it is a mean with associated but unknown variability. Likewise we tend to think that the correlation, out of which the specific fertilizer recommendation is made, is a precise relationship. In actual fact it is a correlation and fairly crude at that because of the approximations, generalizations and extrapolations involved.

It would be unrealistic for a user to try to go through all of the data and assumptions that went into the soil test correlation to derive a more specific correlation to suit his particular needs. There may be an easier way, however, and that could be doing some self-calibration. I am currently involved in a self-calibration project on our Station with our Farm Foreman. Using historical records of soil test analyses, cropping practices, fertilizer application and a concept that I call target soil test values, we are adjusting our fertilizer applications. This concept may be useful for improving the efficiency of soil test fertilizer recommendations by making it much more site-specific.

V. IMPLEMENTATION

A. Factors affecting variability
   (1) Economics (e.g.) costs for precision fertilizer applications
   (2) Physical (e.g.) spreading blended products
   (3) Spacial (e.g.) spot vs field
   (4) Time
   (5) Climate

B. Implications to the user

At this stage, this is where modifications are made to the ideal situation by the practical constraints imposed.

SUMMARY

The implication of all of these factors to the user is that variability is introduced at all five of the areas discussed. Each one influences the next, so it becomes a continuous cycle (or a dynamic circle). To make improvements all parts of the cycle should be considered and action taken at the weakest part.

STRATEGIC FERTILIZER PROGRAMMES FOR INDIVIDUAL FARMERS IN NEW ZEALAND

Steven M. Smith
New Zealand Soil Bureau,
Department of Scientific and Industrial Research,
Dunedin, New Zealand

INTRODUCTION

Pastoral agriculture has been the pre-eminent productive land use in New Zealand since the 1870's. In 1978, pastoral products earned 70% of the total export income and, in spite of recent increases in non-pastoral exports, New Zealand must in the short to medium term still look to the pastoral agriculture sector to significantly increase overseas exchange (Molloy, 1980).

Pastoralism underwent spectacular growth during the "intensification phase" (1920-1970) of New Zealand's land development. During this period stock numbers increased on a nearly constant base of pastoral land area, largely through the use of science and technology (eg. improved ryegrass and clover cultivars, aerial topdressing).

In sharp contrast, the 1970's has been a decade in which stock numbers have reached a plateau at about 100 million total stock units, and fertilizer use has fluctuated widely around a mean of two million tonnes (Molloy 1980). The annual fluctuations in pastoral production during the past decade would seem to indicate elements of economic instability.

Hill and High Country Pastoralism

New Zealand is a predominantly hilly and mountainous country, with 69% (18 million ha) of the total land area having slopes greater than 12°. This is commonly called hill country. Thirty percent of the area of the South Island of New Zealand occurs above 900 m altitude with slopes in excess of 28°, and is referred to as high country. Some statistics on sheep and beef farms from these two areas are given in Table 1.

Table 1. Stock numbers and stock performance data for sheep and beef farms.

South Island	Mean farm area (ha)	1977 sheep numbers (millions)	% all sheep farms	s.u./ eff. ha.	meat kg/ha	wool kg/ha	lambing %	calving %
High Country	10,000	2.0	1.4	0.7	4.6	3.0	82.6	79.9
Hill Country	1,900	4.2	4.1	2.8	29.7	10.6	93.6	81.4

The National Research Advisory Council (NRAC 1978) claims that the hill country sector of New Zealand agriculture has the potential to double its output. However, to achieve this potential, research is needed to help solve the many complex technical problems hill country farmers must face.

One important component in any integrated soil-plant-animal research programme is fertilizer use. Because fertilizer costs range from 0 to 25% of farm input costs (NRAC 1978) there is a need to define the optimal fertilizer levels for both development and maintenance for the range of hill country soil types. Indeed, an often repeated question from hill and high country managers was how little fertilizer could be applied, not how much. The management importance of increasing the efficiency of fertilizer use particularly phosphate, on specific areas of the landscape within an overall hill-high country environment needs to be stressed. Such a strategy involves the development of strategic fertilizer programmes based on good soil information and fertilizer recommendation models rather than the "blanket" fertilizer application strategies of the past.

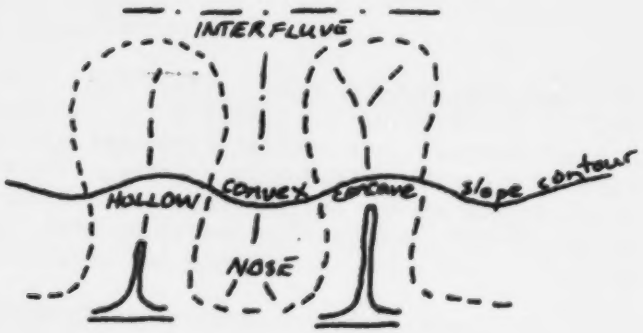
Designing a Strategic Fertilizer Programme in a Hill Country Environment

Several basic steps are involved in this process:

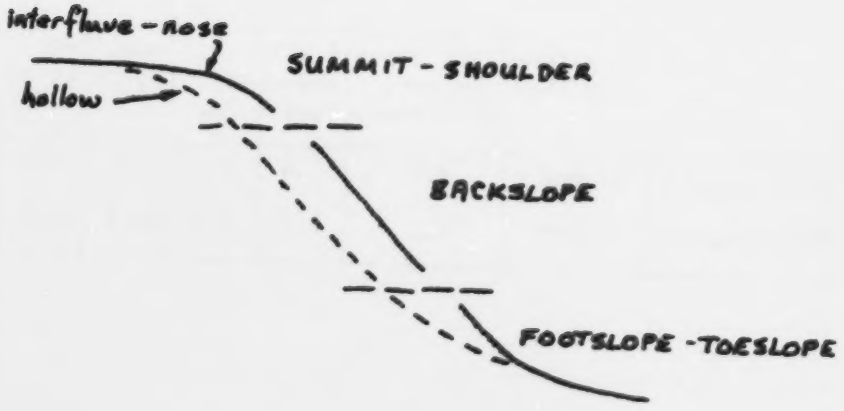
1. Production of a soil map at a scale relevant to farm management levels.

2. Delineaton of appropriate soil-landscape strata. Recognition is given to the influence of ASPECT and CATENARY RELATIONSHIPS on the distribution and nutrient status of the soil (Fig. 1).

Figure 1. Slope Contour



Slope Profile



Aspect - orientation of slopes is classified into four classes; north, south, east, west (i.e. sunny vs. shady).

Slope Contour - slope contour is divided into two strata, distinguished by the curvature of the contour.

a) Hollows: usually lie adjacent to drainage lines and often have the deepest soils.

b) Interfluves and Noses: form watershed between adjacent hollows and often have shallowest soils.

Slope Profile: stratification of slope profile allows the recognition of changes in soil fertility status related to the soil catenary changes within the slope.

3. Soil sampling of landscape strata.

4. Soil testing. Includes available P (Olsen), Ca, Mg, K; pH; P retention; reserve potassium (K_c); sulphur (optional) and soluble salts (optional).

5. Development of fertilizer recommendations, based on the models of Cornforth and Sinclair (1984). For pasture and lucerne, models for phosphorus, sulphur, potassium, magnesium, nitrogen and lime are available, while for crops such as maize, nitrogen, phosphorus, potassium, magnesium and sulphur models are available.

These models have been developed through the accumulated efforts of soil fertility scientists and advisers in the New Zealand Ministry of Agriculture and Fisheries and include relevant research from a wide range of sources. The models are presented in a fertilizer recommendation bulletin which is continually updated as new research findings and information become available. The models used in the bulletin to estimate the requirements of different nutrients and crops differ greatly in complexity. This is because the understanding of factors controlling nutrient requirements and the amount of experimental evidence available for each situation is variable. For example, the phosphorus requirements for developed pastures are based on a vast amount of information and should be very reliable, while recommendations on the nitrogen requirements of pastures are the most general. This is because although many of the factors influencing response to nitrogen are known, there are insufficient data available to measure their effects accurately, or in the case of weather effects, to predict them (Cornforth and Sinclair, 1984).

6. Development of a specific fertilizer strategy for the individual farm based upon properties of soils, farm management levels and economics.

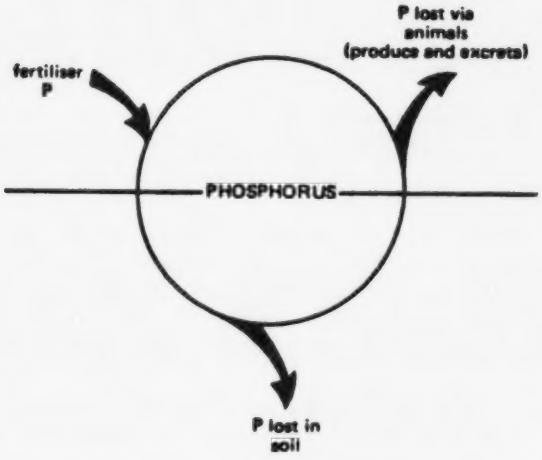
In this discussion an example of determining maintenance phosphate (P) requirments for pasture will be given as P is the dominant fertilizer applied in New Zealand's pastoral agriculture.

In developing the ultimate fertilizer recommendation for a pasture however, optimum quantities of each nutrient are assessed invidually, thus enabling the individual recommendations to be converted into rates of commercially available fertilizer materials.

Phosphorus Requirements for Pasture Maintenance

Phosphate maintenance requirements are estimated by calculating the amount of P required to replace that lost in the soil, by animal transfer and in animal products (Fig. 2).

Figure 2. Simplified phosphate cycle.



The effects of stock type and stocking rate, soil type, land slope, the potential stock carrying capacity of the land and the efficiency of pasture utilization by stock are included in the calculation. The aim is to calculate the minimum amount of P required to maintain the rate of pasture production needed by the farmer.

Animal P loss factors for use in the maintenance P fertilizer model are given in Table 2, and soil P loss factors are given for a selection of New Zealand soil groups (with Canadian equivalents) in Table 3. The latter factor is based on P retention values. Maintenance phosphate tables have been calculated for all combinations of animal and soil P loss factors and a wide range of stocking rates, carrying capacities and pasture utilizations giving 156 alternatives. An example is shown in Table 4.

Table 2. Animal P loss factors.

Stock type	Landform	Animal loss factor (kgP/s.u.)
Sheep, beef, (intensive rotational grazing)	Border dyke irrigation	0.5
	Flat and rolling	0.5
	Easy hill	0.7
	Steep hill	0.9
Sheep and beef	Border dyke irrigation	0.9
	Flat and rolling	0.7
	Easy hill	0.9
	Steep hill	1.1
Dairy cows	Flat and rolling	0.9
	Easy hill	1.1

Table 3. Soil P loss factors.

Soil Group	Canadian	P loss factor
Brown-grey earth	(Luvisol)	0.10
Upland + high country yellow-brown earth	(Brunisol)	0.25
Rendzinas + related soils	(Rendzina)	0.25
Organic soils	(Organics)	0.40
Gley soils	(Gleysols)	0.25
Recent soils (<1000 mm rainfall)	(Regosols)	0.10
Recent soils (>1000 mm rainfall)	(Humic Regosols)	0.25

Table 4. Maintenance phosphate table. (kgP/ha)

Animal loss factor = 0.9 Soil loss factor = 0.25 Carrying capacity = 16

	SR	8	9	10	11	12	13	14	15	16
	PU									
v. low	50	13								
low	60	9	12	17						
medium	70	8	10	12	15	20				
high	80	7	8	10	12	14	18	24		
v. high	90	6	7	9	10	12	14	17	21	29

PU - pasture utilization, %
SR - stocking rate

The relatively large P requirements shown in Table 4, when low stocking rates are associated with very low pasture utilization, represent poor management and wasted fertilizer. The primary aim in such circumstances should be to improve pasture utilization.

Phosphate requirements calculated from the model must be corrected to account for the amount of available phosphate in the soil. This is done by using a modifying factor. The relationship between the modifying factors and Olsen soil P test values depends on the relative yield of pasture being produced and on the P loss category of the soil. An example is given in Fig. 3.

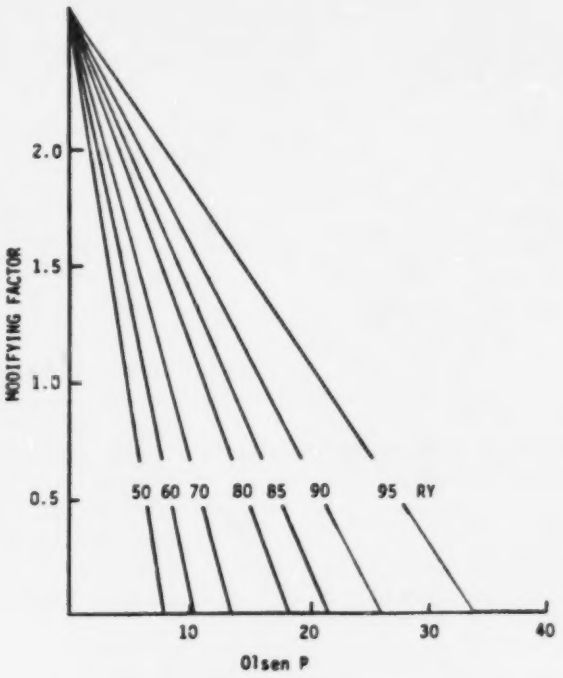


Figure 3. Diagram for correcting maintenance requirements for medium phosphate loss soils.

Procedure

Once soil test values for Olsen P and P retention are available, the alternative fertilizer strategies can be developed.

1. Select relevant maintenance phosphate table from animal P loss factors, soil P loss factors and carrying capacity values, eg. Table 4. (Maintenance P requirements in these tables are for yields up to, but not exceeding 95% of the potential maximum).

2. Use current stocking rate and fertilizer history to identify current pasture utilization for the farm.

3. Alternative longer term strategies include:
   a. maintain current practice
   b. increase pasture utilization and cut fertilizer use at constant stocking rate
   c. increase pasture utilization and stocking rate at constant fertilizer input.
   d. increase stocking rate and fertilizer use at constant pasture utilization.

4. Calculate desired relative yield from : RY = 8550 x stocking rate ÷ carrying capacity ÷ pasture utilization.

5. Use the calculated relative yield and the Olsen soil test value to identify the relevant modifying factor. Multiply the estimated long-term maintenance requirement by the modifying factor to give the short term phosphate requirements. Short term P recommendations are designed to exploit accumulated P in P-rich soils or to increase the P status of low-test soils. Modifying factors close to one should be used for one year only.

Once the alternative fertilizer strategies have been developed for all major nutrients it then becomes a simple matter to calculate the economics of each alternative based on the costs of applying the fertilizer and the expected returns (meat and/or wool) from the additional production. This approach enables those areas on the farm with the greatest potential to be identified and receive priority treatment. This is particularly important if the farm budget limits the size of the area which can be fertilized in any particular year, a normal situation on most hill country farms. In this way the efficiency of fertilizer use is greatly enhanced.

Example
What are the maintenance and immediate phosphate fertilizer requirements for a beef farmer on easy hill country on an upland yellow-brown earth (Brunisol). The land has a potential to carry 16 SU/ha but the farmer intends to carry 12 SU/ha. Pasture utilization is not very good. An averge of 24 kg P/ha has been applied during the last 2 years. Soil P test is 10.

i) Soil loss factor = 0.25 (Table 3)
Animal loss factor = 0.9 (Table 2)
Relevant maintenance P table is Table 4.

ii) Assume that "not very good" pasture utilization equates to the "medium" category, then maintenance P required is 20 kg/ha (Table 4).

iii) Calculate relative yield required for the chosen strategy (see alternative strategies below); suppose strategy (a) is chosen; desired relative yield is 8550 x 12 ÷ 16 ÷ 70 = 91%.

iv) This soil is in the medium soil P loss group, therefore use Figure 3. Using the sloping line for a relative yield of 90% in Figure 3, we see that the "modifying factor" associated with an Olsen value of 10 is approximately 1.5.

v) Assume that strategy (a) is chosen, then the corrected P requirement 20 x 1.5 = 30 kg P/ha. This rate would be applied for 1-2 years.

vi) Possible alternative strategies for the future are (from Table 4):

a) decrease fertilizer to 20 kg P/ha, maintain same stocking rate and increase pasture utilization.

b) decrease fertilizer to 14 kg P/ha, maintain same stocking rate and increase pasture utilization into high category.

c) maintain fertilizer at 24 kg P/ha, increase stocking rate to 14 SU/ha and increase pasture utilization into high category

d) decrease fertilizer to 21 kg P/ha, increase stocking rate to 15 SU/ha and increase pasture utilization into the very high category.

e) increase fertilizer to 29 kg P/ha, increase stocking rate to 16 SU/ha and increase pasture utilization into the very high category.

The last two alternatives are not feasible on most hill country farms because paddock size (often > 50 ha), and terrain largely control grazing efficiency. Even if these were possible, such large increases would not be recommended in a single step.

CONCLUSIONS

Fertilizer models, such as the one outlined above, are now being used extensively by farm advisors and private consultants in New Zealand to improve fertilizer recommendations. In a period of world economic uncertainty, rising farm costs and shrinking traditional markets, the alternatives offered to the farmer by this scheme represent attractive methods to at least maintain current production while reducing fertilizer inputs. Farm management systems now have the flexibility which was lacking in the past when many farmers "religously" applied fertilizer at rates their father or the neighbour next door had applied. Beecroft (pers. comm.) has indicated that from his experience with South Island hill country farmers, too much fertilizer is being applied at current stocking rates and management levels. Often, because of poor soil information (eg. lack of detailed soil maps or poor soil sampling strategy), fertilizer is being applied to soils where very poor, and quite often uneconomic, responses are being obtained. Consequently, delineating those areas on the farm with the greatest production potential from fertilizer application becomes critical and forms the basis for any strategic fertilizer programme. If the patterns reported by Beecroft are widespread, and I suspect they are, then it is likely significant savings could be made to farm input costs without reducing, and in some instances increasing, production levels. It is probably for these reasons the models presented in the fertilizer recommendation bulletin have been widely adopted for testing by New Zealand's farmers.

REFERENCES

Cornforth, I.S. and Sinclair, A.G. (compilers) 1984. Fertilizer and lime recommendations for pastures and crops in New Zealand. Ministry of Agriculture and Fisheries, Wellington. Second Revised Edition, July 1984. 76 p.

Molloy, L.F. (compiler). 1980. Land Alone Endures. Land use and the role of research. New Zealand Department of Scientific and Industrial Research Discussion Paper No. 3. Wellington. 286 p.

National Research Advisory Council (NRAC) 1978. Hill Country Research. National Research Advisory Council. Wellington. 44 p.

Definition of Terms

Animal P-loss factor - phosphate lost in animal produce and via animal transfer in Kg P per stock unit when grazing pasture maintained at 90% of maximum yield.

Carrying Capacity - the number of stock units which could be carried per hectare with an overall pasture utilization of 90% when pasture production is maintained at 95% of the maximum yield and with an annual dry matter intake of 550 kg per stock unit.

Maintenance Fertilizer - a rate of fertilizer application designed to maintain a near constant annual production and soil nutrient status by replacing nutrients lost from the cycling pool of plant available nutrients.

Maximum yield (of pasture) - the average annual yield possible from a well managed pasture whose production is not limited by the supply of nutrients other than N.

P retention - the amount of P retained by a soil when shaken with a buffered solution initally containing 1000 ppm P for 16 hours as a percentage of the P in the initial solution (Saunders, W.M.H. (1965), N.Z. Journal of Agric. Res. 8: 30).

Relative Yield - yield expressed as a percentage of the maximum (or potential) yield.

Soil P-loss factor - phosphate lost from the cycling pool by immobilization, leaching or erosion as a percentage of that taken up by plants in pasture maintained at 90% maximum yield.

Soil P test - the standard New Zealand MAF bicarbonate extractable phosphate test (Olsen) expressed as ppm P in soil.

Standard stock unit - a stock unit with an annual dry matter intake of 550 kg. This corresponds to an ewe which is 55 kg at mating and has 1 lamb weaned per year.

FOLIAR ANALYSIS FOR DEFICIENCY DIAGNOSIS AND FERTILIZER PRESCRIPTION IN FORESTRY: VARIABILITY CONSIDERATIONS

T.M. Ballard

Departments of Soil Science and Forest Resources Management
University of British Columbia

ABSTRACT

Variability considerations are involved in sampling, analysis and interpretation, where foliage chemical properties are used for nutritional diagnosis and fertilizer prescription in forestry. To minimize sampling expense while enabling useful interpretations, sampling must conform to specific guidelines. The appropriate sampling intensity must be based not only on a prediction of within-stand variability, but also on some knowledge of regional nutrition problems and interpretive sensitivity. Compositing of samples saves analytical time and money; the consequent loss of statistical information should not be a serious disadvantage for routine diagnosis and prescription, if the sampling intensity is adequate. Available laboratory methods for routine analyses offer adequate precision and accuracy for routine diagnostic and prescriptive purposes. However, the use of reference samples is recommended to ensure analytical quality control.

INTRODUCTION

Nutrient deficiency diagnosis and fertilizer prescriptions can use foliar analysis instead of, or in addition to, soil analysis. With both soil and foliage, calibration determines the relationship between analytical data and the response of the crop to fertilizer. This relationship is subsequently used for diagnosis and prescription. The relationship may be poor if response-limiting non-nutritional factors are ignored, or if inappropriate soil or foliage variables have been selected for analysis. Applications of the relationship may be invalid if they fail to use the same sampling guidelines and analytical methods employed for the calibration which established the relationship.

The quality of both the calibration and the subsequent applications can also be strongly affected by variability of samples and by analytical precision and accuracy. The purpose of this paper is to explore these aspects of foliar analysis for routine nutritional diagnosis and prescription in forestry.

Specific objectives are (1) to identify some of the important factors associated with variation among foliage samples, (2) to discuss the sample variability observed where these factors are controlled (and the implications for sampling intensity), (3) to indicate the levels of precision and accuracy which we have observed in routine laboratory analysis of foliage for forestry purposes, and (4) to suggest a few procedures which reduce analytical costs while enabling checks for quality control.

FACTORS INFLUENCING VARIATION OF FOLIAGE SAMPLES

Factors known to influence foliar nutrient levels include species; season; foliage year (in trees with persistent foliage); weather and climate; crown class; crown position; dust contamination; stress due to insects, disease, mechanical damage, and reproductive development; as well as site nutrient status and competition (Morrison 1974; van den Driessche 1974; Turner et al. 1978). If one wished to sample for estimating nutrient content of the whole forest canopy, the whole spectrum of variation associated with these factors would have to be sampled. For routine diagnostic and prescriptive purposes, however, only an index of nutrient status is needed, so that only a portion of the spectrum is needed: ideally, the portion which is most closely related to nutrient deficiency or sufficiency status.

For conifer stands (other than larch) in British Columbia, the following guidelines have been suggested (Ballard and Carter 1983):

1) Sample after the growing season, preferably between September 15 and December 15.

2) Sample between the top quarter and the bottom half of the live crown (of trees with ample foliage); in any case, avoid sample whorls very near the leader or (if branch mortality is occurring) near the bottom of the live crown.

3) Collect current-year foliage (for routine purposes), representing at least two shoots per branch and at least two (preferably non-coning) branches per tree.

4) Confine sampling to dominant and co-dominant trees (or to those trees least subject to competitive disadvantage).

5) Avoid trees which appear abnormally stressed by insects, disease, mechanical damage, and reproductive development.

6) Avoid trees contaminated by road dust, if iron analysis is to be performed.

The first three of these guidelines are somewhat controversial. Some physiologists have argued that sampling should be done during the growing season, because nutrient levels then may be more closely related to deficiency or adequacy (Waring and Youngberg 1972). However, levels of many nutrients fluctuate dramatically during the growing season, phenological development of different stands may be several weeks out of phase, and a sampling program may extend over several weeks, with no opportunities to re-visit sampled stands. Relative stability of fall nutrient levels, allowing consistent interpretation, makes fall sampling most commonly preferred for routine forestry purposes.

Sampling from the bottom of the live crown is easy, and in well spaced, pruned stands, it is preferred by some practitioners. However, in dense, unpruned stands, foliar nutrient levels at the bottom of the live crown, where branch mortality is occurring, may poorly represent the overall stand nutrient status. Work by Reemtsma (personal communication) has indicated that nutrients in foliage from the uppermost whorls of Norway spruce are also not characteristic of most of the tree. With very young seedlings, one may be obliged to collect foliage from almost all parts of the tree (excluding the uppermost whorl), to obtain sufficient sample for analysis.

Current-year foliage gives useful interpretations for most nutrients. For some nutrients, however, previous-year rather than current-year foliage, or a comparison of the two, yields better interpretations. Sampling guidelines for different parts of the world consequently vary in this respect, depending on which nutrients are of greatest concern. The added cost of concurrently sampling previous-year foliage is small, but the costs of sample preparation and analysis are sufficiently high that most of us in this region are content to rely on current-year foliage.

The shoots to be sampled are sometimes specified very precisely, to reduce variation and enable interpretation based on some refinements of data expression (e.g. mass of nutrients per shoot). For example, in well developed trees of some species (e.g. Douglas-fir), one can specify a fixed ratio of branch terminal shoots to terminal shoots of first-year laterals, from a particular whorl, when making up the sample representing a tree (Lavender 1970). However, for species like lodgepole pine, which forms laterals less consistently, or white spruce, in which many branch terminal buds may fail to flush, this guideline refinement is seldom practical.

In routine work, one can hardly afford to re-sample all stands over a period of several years. However, year-to-year variations in nutrient levels associated with climatic fluctuations are a problem in evaluating some nutrients. With boron, for example, one may be obliged to use somewhat different interpretations, depending on whether samples were collected in wet versus dry years (Braekke 1979).

VARIABILITY AND THE PREDICTION OF ADEQUATE SAMPLING INTENSITY

Although the above sampling guidelines reduce variability, there is still enough variation to require sampling of more than one tree for characterization of a stand. How many trees are needed to estimate stand nutrient status? Let us imagine that we wish to estimate a stand's foliar nitrogen concentration within 10 percent of the mean, and that we want to collect just enough samples to meet this requirement, without first conducting a preliminary study of variation within that stand.

There are two major problems here. First, there is a chance that the true mean deviates from the sample mean by more than the specified allowable error. (Often we set the allowable probability for this at alpha = 0.05). Second, there is a chance of under-estimating within-stand variation and thereby underestimating the required sampling intensity.

We could deal with this second problem straightforwardly in terms of beta probability, if we had the luxury of obtaining a preliminary sample from the stand, recognizing (for example) the 50 percent chance that the stand sample variance underestimates the stand population variance. The operational problem in forestry is somewhat different. Without preliminary sampling to estimate variation within a particular stand, sampling intensity requirements must be based on information previously obtained from other stands. Thus we need to know something about the between-stand variation of within-stand variability.

Table 1 presents some data on variability of foliar nutrient concentrations and the implications for sampling intensity to achieve various levels of precision. The data represent second-growth Douglas-fir stands sampled over a wide range of site conditions in the Vancouver Forest Region. In each stand, 15 trees were sampled, and the C.V. (coefficient of variation) for each nutrient was calculated. The 95th percentile C.V. is the coefficient of variation which is expected to exceed that found in 95 percent of sampled stands. This C.V. and the t-statistic (for 14 degrees of freedom and alpha = 0.05) were used to calculate the required sampling intensities ("k" values) which are tabulated. Thus, in 95 percent of sampled stands, there should be about a 95 percent chance of attaining the target precision where the table is followed. And in some of the remaining 5 percent of stands, there is still a better than even chance. This statistical evaluation could be improved, but it is probably adequate, considering our uncertainties about appropriate levels of precision and confidence.

TABLE 1. Coefficients of variation and implications for foliar sampling intensity in Douglas-fir stands.

Nutrient	No. of Stands Sampled	Ave. C.V.	95th %ile* C.V.	k** where allowable error is			
				10%	20%	30%	50%
N	10	10.2	15.3	11	3	1	1
P	10	17.4	38.5	68	17	8	3
K	10	17.6	30.4	42	11	5	2
Ca	10	25.9	36.1	60	15	7	2
Mg	10	17.1	25.4	30	8	3	1
S	10	11.8	20.3	19	5	2	1
Mn	10	34.3	49.8	114	29	13	5
Zn	10	39.9	66.8	205	51	23	8
B	10	25.6	43.8	88	22	10	4
aFe***	10	27.8	46.6	99	25	11	4

* 95 percent of sampled stands are estimated to have a C.V. of this magnitude or less.

** k is the number of samples needed to estimate the mean within the specified allowable error, with 95% confidence (i.e. $\alpha = 0.05$), in 95% of sampled stands.

*** aFe represents the physiologically active Fe fraction.

The table indicates that we should sample about 11 trees to estimate a stand's foliar nitrogen concentration within the arbitrarily specified allowable error of 10 percent. But is 10 percent the appropriate magnitude for allowable error, and is the arbitrarily specified value of $\alpha = 0.05$ appropriate? Ideally, there are statistical answers to these questions, but in practice, because of data limitations, we use subjective judgement, based on the following rationale.

If a nutrient is rarely deficient and fertilization with that nutrient is rarely contemplated, we can tolerate low precision and confidence. That is, if we subtract a large allowable error from the measured value for such a nutrient, the difference will usually still be safely above the critical deficiency threshold, and we will rarely make bad management decisions from the data. Also, if diagnostic calibration is imprecise, so that one is uncertain about whether a precise estimate of the nutrient level could be

interpreted as deficient or not, one cannot justify extra sampling to obtain a more precise estimate of nutrient level. In contrast, if a nutrient commonly is in the range from severe to slight deficiency and we can interpret levels fairly precisely, we should like to attain high levels of precision and confidence in our estimation of those levels.

Nitrogen deficiency is the most common and most serious nutritional problem in forests of British Columbia; consequently I would place highest demands for precision and confidence on that. Among the macronutrients, S and P probably rank next, but substantially lower, in importance (except in hemlock, where P deficiency is perhaps about as common and serious as N deficiency). Mg problems have been tentatively inferred from foliar analysis of some interior white spruce plantations. Among the micronutrients, B deficiencies occur in a few places, Fe and Cu problems appear to occur sometimes in interior spruce plantations and lodgepole pine, and the possibility of Zn deficiency has been suggested in some hemlock stands. For most of these micronutrients, interpretive precision is low.

Taking these considerations together with the data of Table 1, analogous data from several lodgepole pine stands, and less comprehensive data for a few other species, I am inclined to suggest that sampling 15 to 20 trees per stand is reasonable as a general guideline for operational practice in forestry. If one has reason to suspect specific nutritional problems in a sampling locality, the estimate might be revised.

Sometimes, unusually large variation can be anticipated from evidence available before foliage is collected. Data obtained by sampling according to micro-relief differences in a lodgepole pine stand (Ballard 1980) and according to spectral reflectance differences in interior Douglas-fir (Murtha and Ballard 1983) suggest that, in such cases, the sampling requirements can be reduced by stratified sampling. From our limited information on this, I have tentatively inferred that where two or more major strata are sampled, 10 trees per stratum might usually be sufficient for overall characterization of a stand.

ANALYTICAL PRECISION AND ACCURACY

A discussion of analytical precison and accuracy must necessarily make reference to particular methods. For analysis of British Columbia conifer foliage, we grind samples in a "coffee-grinder". However, for Pinus caribaea from Malaysian plantations, some grasses, and some other foliage, we have found that grinding yields fibrous and powdery fractions which tend to separate. Such samples require chopping, before grinding, to improve sub-sampling for analysis. We dry samples at 70 degrees C. To digest samples for analysis of N, P, K, Ca, Mg, Al, Mn, and Zn, we use the method of Parkinson and Allen (1975), which employs concentrated sulfuric acid,

lithium sulfate, selenium, and 30 percent hydrogen peroxide. After digesting 1 g of foliage, we dilute to 100 mL with demineralized water. N analysis by the Berthelot (phenol-hypochlorite) reaction and P analysis (as the unreduced vanado-molybdate complex) are done on a Technicon autoanalyzer. The metals are analyzed by atomic absorption (solution aspiration) with an air-acetylene flame. We do not routinely use lanthanum for the Ca analysis. Although Al is not a nutrient, we have been including Al analysis to examine relationships with phosphorus nutrition problems. For Cu and "total" Fe analysis, we digest 1 g of sample in boiling nitric acid, with repeated additions of 30 percent hydrogen peroxide, and dilute to 25 mL with demineralized water, and then analyze by atomic absorption, as above. For B analysis, we use the dry ashing and azomethine H method of Gaines and Mitchell (1979). For S analysis, we use the Fisher sulfur analyzer, as described by Guthrie and Lowe (1984). For "active" Fe analysis, we use a modification of the HCl extraction method of Oserkowsky (1933), and atomic absorption spectrophotometry.

Examples of the precision we have obtained by these methods are shown for a coniferous and a deciduous sample in Table 2. Coefficients of variation for all analyses are within 8 percent overall, and below 5 percent for about 9 out of 12 analyses. For routine diagnostic and prescriptive purposes, I believe such precision is adequate; indeed, it seems adequate for most research purposes involving foliar analysis.

Analytical accuracy of these methods can be inferred by using them to analyze foliage reference sample material obtained from the U.S. National Bureau of Standards, and comparing the results with the NBS certified values. (The NBS uses essentially the best available methods, most of which are far too expensive for routine use.) Table 3 presents ratios of NBS values to the average values obtained in our laboratory. Such ratios could be used as multipliers, if one wished to estimate actual values from analyses performed in our laboratory. Ratios much over 1.00 presumably indicate low recovery by our routine methods.

Although the NBS does not give a certified value for S, we assume that our measured S values are sufficiently accurate. For a discussion of the method and its accuracy, see Guthrie and Lowe (1984). The major discrepancies in Table 3 are for Ca, Mn, and Fe. Presumably our Ca recovery would be higher if we added lanthanum for atomic absorption. However, because Ca deficiency is extremely rare in British Columbia forests, the extra procedure would be justified, for routine diagnostic or prescriptive purposes, only where preliminary analysis indicates an unusually low value. Mn recovery appears a bit low, but after several thousand foliar analyses, we have only inferred Mn deficiency or near-deficiency in two stands, so the analytical recovery is presumably adequate for routine diagnosis and prescription. Recovery of the total Fe

TABLE 2. Examples of analytical precison for coniferous and deciduous foliage. Units for the mean and standard deviation are given in the Nutrient column. Coefficients of variation are in percent. Each analytical replicate represents a different batch of analyses.

Pinus radiata sample:

Nutrient	Mean	Std. Dev.	Coeff. Var.	n
N, %	1.238	0.0245	1.98	4
P, %	0.142	0.0033	2.30	4
K, %	0.948	0.0227	2.40	4
Ca, %	0.216	0.0047	2.18	4
Mg, %	0.117	0.0043	3.64	4
S, %	0.121	0.0028	2.34	6
Al, %	0.023	0.0011	4.59	4
Mn, ppm	260.	6.12	2.36	4
Zn, ppm	31.5	1.66	5.26	4
Fe, ppm	67.	1.00	1.49	4
Cu, ppm	4.7	0.17	3.69	4
B, ppm	15.7	0.77	4.90	5

Eucalyptus nitens sample:

Nutrient	Mean	Std. Dev.	Coeff. Var.	n
N, %	1.740	0.0442	2.54	4
P, %	0.133	0.0019	1.45	4
K, %	0.754	0.0298	3.95	4
Ca, %	0.531	0.0108	2.04	4
Mg, %	0.097	0.0051	5.24	4
S, %	0.160	0.0041	2.58	6
Al, %	0.012	0.0007	5.89	4
Mn, ppm	1010.	12.2	1.21	4
Zn, ppm	18.	0.71	3.93	4
Fe, ppm	39.	1.22	3.14	4
Cu, ppm	9.4	0.67	6.85	4
B, ppm	14.8	1.18	7.96	5

TABLE 3. U.S. National Bureau of Standards (NBS) orchard leaf sample: ratios of NBS average values to average values obtained at the UBC Forest Soils Laboratory (FSL).

Nutrient	(NBS Values)/(FSL Values)
N	1.02
P	1.04
K	1.04
Ca	1.20*
Mg	1.01
S	(NBS value not certified)
Mn	1.12
Zn	1.00
Fe	(routine methods unreliable)
Cu	1.03
B	1.00

*FSL routine Ca analysis by atomic absorption does not use lanthanum addition

amount certified by NBS is extremely poor, not only by our method, but apparently by all routine methods, including nitric-perchloric digestion (Zasoski and Burau, 1977). Morever, work by Oserkowsky (1933) with fruit trees and by Zech (1970) with Scots pine has demonstrated that analysis of total Fe has very little diagnostic value, but that analysis of "active" Fe is very useful. Recent work by Majid (1984) with lodgepole pine also supports the diagnostic usefulness of "active" Fe. Consequently, we use "active" Fe analysis for diagnostic purposes, and the low recovery of total Fe is seldom a problem in our routine work. (We have not yet adopted a routine method for foliar Mo analysis, so I am unable to report on that element.)

REDUCING ANALYTICAL COSTS WHILE MAINTAINING QUALITY CONTROL

If one is unwilling to accept the risk that some stands may be more variable than anticipated (e.g. more variable than the 95th percentile), or if one is doing research (e.g. testing for significance of differences between means), then analysis of individual samples may be unavoidable. Such analysis is expensive, so that budget limitations could severely limit the number of stands which could be evaluated in this way.

For routine diagnostic and prescriptive purposes, however, individual sample analysis is unnecessary. Instead, all samples of one species within a stand (or stand stratum) can be composited, with each individual sample making the same mass contribution to the composite. Ideally, replicated analysis of this composite will yield the same mean value as would be obtained by averaging data from the individual samples. It is true that, to the extent nutrient ratios may be used diagnostically, the ratio of averages will differ from the average of individual sample ratios. However, the diagnostic difference is probably seldom large enough to justify the extra expense of individual sample analysis. With high analytical precison, as few as two or three replicate analyses of the composite should be sufficient (but the analyses should be done in different batches).

In cases where individual sample analyses are done, budgets seldom allow analytical replication, so that the analytical variation contributes to the apparent variation between samples. In this case, one needs another means of checking analytical precison. We provide this by preparing a few kilograms of ground and mixed conifer needles as a laboratory reference sample, from which we take a subsample for inclusion with each batch of samples undergoing analysis. Checking analytical data from this reference subsample against the data previously obtained for the same material will indicate whether something has gone wrong with a batch.

Those who send foliage away for analysis should include a subsample of U.S. NBS foliage material with at least one batch of samples, to check the laboratory's analytical accuracy. They should also make up their own large reference sample and include at least one reference subsample from it with each batch of samples. Comparing values obtained from such subsamples will provide a basis for evaluating the laboratory's performance. Over time, as samples are sent to different laboratories, or as methods or personnel change within a laboratory, the reference sample data will prove invaluable.

CONCLUSIONS

Foliar analysis can be useful for nutritional diagnosis and fertilizer prescription in forestry. However, its value for such purposes strongly depends on designing and implementing a sampling and analysis program which balances variability, costs, and interpretation needs. The appropriate balance uses sampling guidelines to minimize variation among samples, reducing replication requirements and sampling costs. It seeks the minimum sampling intensity consistent with interpretation needs. It strives for a reasonably high level of precision and accuracy in inexpensive, routine analytical methods. And it reduces analytical costs by analyzing composite samples wherever possible, recognizing that little variability information is needed for routine interpretations, if one has taken steps to assure adequacy of sampling and analytical quality control.

ACKNOWLEDGEMENTS

The Research Branch, B.C. Ministry of Forests provided funds for testing of foliar sampling and analytical methods. The Vancouver Region's Silviculture Section in the Ministry funded the sampling and analysis on which Table 1 is based. Sample material for the analyses presented in Table 2 was provided by Dr. G.M. Will of the New Zealand Forest Research Institute. Laboratory analyses were performed by J. Lansiquot, R. Lowe and E. Wolterson.

LITERATURE CITED

Ballard, T.M. 1980. Foliar analyses, nutrient deficiency diagnoses, and tentative fertilizer recommendations for four lodgepole pine stands. Contract Res. Report to the B.C. Forest Service for the Reserch Section, Prince George Forest Region. 17 pp.

Ballard, T.M. and R.E. Carter. 1983. Evaluating forest stand nutrient status. B.C. Min. For. 76 pp.

Braekke, F.H. 1979. Boron deficiency in forest plantations on peatland in Norway. Medd. Norsk Inst. f. Skogsforskning 35: 213-236.

Gaines, T.P. and G.A. Mitchell. 1979. Boron determination in plant tissue by the azomethine H method. Comm. Soil Sci. Plant Anal. 10: 1099-1108.

Guthrie, T.F. and L.E. Lowe. 1984. A comparison of methods for total sulphur analysis of tree foliage. Can. J. For. Res. 14: 470-473.

Majid, N.M. 1984. Some aspects of boron, copper and iron nutrition of lodgepole pine and Douglas-fir. Unpubl. Ph.D. thesis, Dept. of Soil Science, Univ. of B.C., Vancouver. 172 pp.

Morrison, I.K. 1974. Mineral nutrition of conifers with special reference to nutrient status interpretation: a review of the literature. Can. For. Serv. Publ. No. 1343. 74 pp.

Murtha, P.A. and T.M. Ballard. 1983. Foliar nutrients and photo interpretation of Douglas-fir stress. Can. J. Remote Sensing 9: 99-110.

Oserkowsky, J. 1933. Quantitative relation between chlorophyll and iron in green and chlorotic pear leaves. Plant Physiol. 8: 449-468.

Parkinson, J.A. and S.E. Allen. 1975. A wet oxidation procedure for the determination of nitrogen and mineral nutrients in biological material. Comm. Soil Sci. Plant Anal. 6: 1-11.

Turner, J., S.F. Dice, D.W. Cole, and S.P. Gessel. 1978. Variation of nutrients in forest tree foliage - a review. Univ. of Wash. Coll. For. Res. Inst. For. Prod. Contrib. No. 35. 32 pp.

van den Driessche, R. 1974. Prediction of mineral nutrient status of trees by foliar analysis. Bot. Rev. 40: 347-394.

Waring, R.H. and C.T. Youngberg. 1972. Evaluating forest sites for potential growth response of trees to fertilizer. Northwest Sci. 46: 67-75.

Zasoski, R.J. and R.G. Burau. 1977. A rapid nitric-perchloric acid digestion method for multi-element tissue analysis. Comm. Soil Sci. Plant Anal. 8: 425-436.

Zech, W. 1970. Nadelanalytische Untersuchungen ueber die Kalkchlorose der Waldkiefer (Pinus silvestris). Z. f. Pflanzenernaehr. Dueng. Bodenk. 125: 1-6.

QUANTITATIVE DEFINITIONS OF STABILITY CLASSES AS RELATED TO POST-LOGGING CLEARCUT LANDSLIDE OCCURRENCE

Mark Sondheim
B.C. Ministry of Environment

Terry Rollerson
MacMillan Bloedel Limited

Since the early 1970's a number of forest companies and government agencies in British Columbia have become increasingly concerned about the loss of slope stability following logging in coastal areas. This concern has been fueled by a growing awareness of the costs and hazards associated with slope failure. Detrimental impacts include not only forest site loss but damage to other resources such as fisheries. As well, as urban dwellers move more into the rural and forest environment, they sometimes find themselves at risk from both natural and logging related landslides. These issues have resulted in many areas being placed off limits to logging. However, such actions can be a mixed blessing, for if unnecessary withdrawal of lands from harvesting should occur, there may be significant economic consequences to local logging operations and communities. Within industry and government there is agreement in principle that lands prone to post-logging slope failure may demand different management, including in some cases their exclusion from harvesting. Questions remain over the techniques of identifying those areas. More rigorous, more quantitative methods have been sought. After a brief review of current practices, this paper presents a case example of what is termed a 'statistical - geographical' approach.

Approaches to Stability Mapping

Slope failure resulting from logging practices can be of one of two types. Occurring within the surficial material, the first and more common type has to do with clearcuts. It is presumed to be principally a function of tree root deterioration and changes in hillslope hydrology. The second type of slope failure is related to the placement and construction of logging roads. Cut and fill operations can result in oversteepened slopes and inadequate or unmaintained drainage systems can lead to erosion from unplanned concentrations of water. The present study is concerned with stability mapping as related to clearcut induced failures only.

Slope stability mapping in British Columbia was initiated by MacMillan Bloedel Ltd. in 1973 in the Queen Charlotte Islands (Bourgeois 1974) and has continued to gain momentum since that time. This mapping, primarily in unlogged watersheds, is carried out at a scale of 1:20000 or 1:50000, generally using air photo interpretation with reconnaissance level groundtruth. For example, one day of field checking may suffice for every 800ha mapped at a scale of 1:20000 or every 5000ha at a scale of 1:50000. Depending upon the user's needs, coverage may extend over the whole of a watershed or only over selected steepland areas.

The mapping procedure typically begins with the production of a surficial geology map following the terrain classification system developed by the British Columbia Ministry of Environment (Ryder and Howes 1984, ELUC Secretariat 1976). In this system each polygon or delineation is labelled with a series of codes describing the parent materials, their textures and ground surface morphology, and any active geomorphic processes. In the last several years mappers have begun adding slope class and drainage class codes to these labels. Frequently the labels are quite complex with the overall effect that use of the maps is best suited only for other geomorphologists.

After the surficial geology map is produced, each polygon is assessed according to its estimated stability following logging. MacMillan Bloedel has established the precedent of a five class rating in which class five is the most sensitive and class one the most stable. A polygon may belong to one and only one class. With each polygon having only a single character label, these maps are very easy to use, particularly by resource managers who have neither the time nor the expertise to make such judgements.

The methodology of making the stability class assignments is usually difficult to establish precisely. Any polygon with natural failures is categorized as class 5. Other class definitions are more subjective and highly dependent upon the local knowledge of the mapper. There are at least two avenues toward greater quantification and more consistency: one deterministic and one empirical.

The deterministic approach attempts to adapt existing engineering slope stability equations to extensive, field mapping systems. The classic "factor of safety" (Terzaghi and Peck 1967) techniques of soil mechanics demand data on the depth to the expected failure plane, the slope and shape of the expected failure plane, and the density and the angle of internal friction of the slope material. Root strength, slope hydrology and expected storm intensities and duration are also required. Because of the high cost of acquisition, such data typically are collected only in

very site specific situations. Broad generalization to many coastal watersheds is questionable as many of these factors are highly variable. Variations in land surface and bedrock topography, stratigraphic sequences and depths, and vegetation and climate are all contributing sources of heterogeneity. As a result of these problems, the authors do not consider strictly deterministic techniques for estimating stability classes to be viable in a general mapping context.

The empirical approach advocated here depends on statistical inference based on frequencies estimated over large geographical areas. It was developed in part from a more general project investigating landslide characteristics and the attributes of landscape units subject to post-logging landslide activity (Rollerson 1984). The procedure involves four main steps:

(1) terrain mapping and data collection in a series of logged areas viewed as typical of a larger region;

(2) assigning terrain polygons to arbitrarily numbered classes of a terrain classification;

(3) calculating for each class several stability statistics, including the probability of post-logging failure; and

(4) grouping the terrain classes into a smaller number of connotatively numbered classes of a stability classification.

Steps 3 and 4 may be repeated for various terrain classifications, based on different sets of variables and/or different class breaks of the same variables. If this is done the results may be compared to determine whether the classifications vary significantly in terms of their stability implications. The present analysis proceeds only to this point.

Of course the real value of the exercise would come from applying the knowledge gained on the study areas to geomorphically similar, unlogged areas. Also of merit would be to assess independently two geomorphically equivalent sets of study areas and to apply the results from each to the other. This would help ascertain the effectiveness of the approach. The database in the present study is too small to divide in two for this purpose.

Another limitation of the study concerns landslide magnitude and routing. Neither variable is taken into account. Because landslide area is often not well correlated with landslide volume, estimating magnitude accurately can be quite difficult without very detailed

field work. The routing of a slide, especially whether or not it reaches the drainage network, is as important from a management perspective as magnitude. The route followed depends on a number of interacting factors, including the type and magnitude of the slide and the local hillslope morphology. The present work is directed specifically at landslide occurrence and frequency.

Study Area

The study examines 168 polygons covering about 10km2 distributed in eight selected clearcut areas. The areas lie within the Vancouver Island Ranges physiographic unit (Holland 1976) and are located between 5 and 20km inland from Barkley Sound along the southwestern coast of Vancouver Island. Dominant elevations within the study area range from 100 to 800m above sea level. Glacially sculpted during the Pleistocene and previous epochs, the local mountains rise to roughly 1300m.

Falling within the coastal western hemlock biogeoclimatic zone (Krajina 1969/70), the region is dominated by western hemlock (Tsuga heterophylla), balsam fir (Abies amabilis), and western red cedar (Thuja plicata), and sitka spruce (Picea sitchensis). On stable slopes below the subalpine the majority of soils fall within the Ferro-Humic Podzolic Great Group (CSSC 1978). The temperate climate is characterized by abundant rainfall and strong winter storms from the Pacific Ocean. Climate stations from Kennedy Lake (directly within the study area), Bamfield (within 5km of the study area) and Tofino Airport (about 40km to the northwest) show a mean annual temperature of approximately 8.9°C and an associated standard deviation of 0.5°C. The mean annual precipitation is about 3300mm, with the winter months accounting for roughly six times more precipitation than the summer months. The maximum 24h rainfall is on the order of 200mm. Intense rains are often associated with strong winds generated by cyclonic winter storms moving from west to east. The extent to which these conditions lead to local rain shadowing effects is not known.

The bedrock lithology is highly mixed, consisting of extrusive and intrusive complexes and some metamorphics. Major fault structures run northwest - southeast with secondary faults nearly orthogonal to this. Field observations do not suggest any obvious relationships between slopes with failures and the orientations of faults, joints or bedding planes. The surficial materials of the steeper slopes are dominated by till, colluvium and minor amounts of bedrock, fluvioglacial and fluvial deposits. The till is generally found in two strata, a pedogenically weathered phase overlaying an unweathered, massive, basal till. Where slides occur in till, it is

often at this interface or just above it. Less often the failure plane is within the basal till. Typically the colluvium shows strong soil development down to the bedrock surface, and on unstable slopes, it is this surface which usually serves as the failure plane.

Database

The study was confined to a limited geographic area in an attempt to minimize climatic variability. Further restrictions included consideration only of areas containing clearcuts that were from 5 to 20 years old and that occurred on slopes inclined at least 20°. The lower age limit was imposed to allow time for root strength deterioration to take place and to provide a reasonable opportunity for large storms to act on the logged terrain. The upper age limit was required because well advanced plantation regeneration can often mask the presence of smaller landslides. Slopes less than 20° were excluded as they did not exhibit any evidence of post-logging failure. Otherwise, the eight study areas were selected so as to sample as wide a range of hillslopes and terrain types as possible within the region.

Following the terrain mapping system previously outlined, the areas were inventoried at a scale of 1:20000. An effort was made to keep the polygons as homogenous as possible with respect to both surficial geology and topography. Each polygon was visited in the field and a set of data describing its geomorphic and geometric attributes was recorded. The data include: surficial materials present, including exposed bedrock, in order of dominance; the presence or absence of natural failures; slope morphology, including the presence or absence of gullies; soil type; elevation; slope angle; slope aspect; and slope position. For purposes of polygon area calculations and other cartographic measurements, map unit boundaries were plotted on 1:10000 scale topographic maps produced specifically for the project. A Zeiss Planicart E3 stereoplotter was used for creation of the topographic bases and transfer of polygon boundaries.

The final item in the data set is the number of post-logging, clearcut failures in each polygon. Landslides within or on the borders of clearcuts were assumed to have been caused by events, such as loss of root strength, initiated by tree harvesting. Thus, no attempt was made to prove that these failures would not have happenned if logging had not taken place. Slides identified with clearcutting were found in 34 of the 168 polygons in the study; these 34 polygons contained a total of 77 slides.

Landslides not clearly identifiable on 1:20000 aerial photography were excluded from the study. Experience indicates that usually a landslide must be 300 to 500 square metres or larger to be discernible at this scale. In addition, data from both southwestern Vancouver Island (Rollerson 1984) and the Queen Charlotte Islands (Chatwin and Rollerson 1984) reveal that although smaller landslides are typically very common, they contribute only marginally to the total area of the land base disturbed by landslides. Consequently any landslide smaller than 300 square metres was ignored even though it may have been quite obvious in the field.

Development of Terrain Class Stability Statistics

Each polygon of the terrain map is treated as a single sample or response unit. The polygons are placed into a classification according to a set of specific class definitions. For each terrain class several simple statistics can then be generated based on the post-logging failures of the class members. First, the probability of post-logging failure within a given class can be defined:

(1) $$Pf(i) = Npf(i)/Np(i)$$

where Pf(i) is the probability of post-logging failure occuring within any given polygon within class i,
Npf(i) is the number of polygons with one or more failures in class i, and
Np(i) is the number of polygons in class i.

A similar approach has been developed for forested watersheds in Japan (Tsukamoto, Ohata, and Noguchi 1982). In that study the probabilities of natural slope failures were determined within simple topographic units defined on the basis of drainage features.

Also useful for describing a class within a study area are three other ratios:

(2) $$Rfa(i) = Nf(i)/Ap(i)$$

(3) $$Rfpf(i) = Nf(i)/Npf(i)$$

(4) $$Pata(i) = 100*Ap(i)/At$$

where Rfa(i) is the ratio of the number of failures in class i to the total area in hectares of all polygons in class i;
Rfpf(i) is the ratio of the number of failures in class i to the number of polygons with one or more failures in class i;

Nf(i) is the number of failures in class i;
Ap(i) is the total area of all polygons in class i;
Pata(i) is the percentage of the total area in the study which is occupied by class i;
At is the total area included in the study.

Once a land manager knows the number of hectares of a planning area occupied by a given terrain class, the ratio of failures to hectares, Rfa(i), can provide him with an idea of how many failures may result if logging proceeds on land of that class. The ratio of failures to polygons with failures, Rfpf(i), gives a crude indication of the severity of slope failure which may occur in polygons of a given class. Thus, Pf(i), Rfa(i), and Rfpf(i) are all closely related to the notion of stability. Pata(i), the class area to total area percentage, suggests how common these various levels of stability appear to be.

The evaluation of any particular polygon or area is entirely dependent upon the terrain class into which it falls. This raises the question of the validity of the classification being used. Specifically, are there other defensible classifications? If so, does use of them yield significantly different results? As the example discussed below demonstrates, the answer to the first question is definitely yes; the landscape may be categorized in a number of ways. One classification may emphasize topography, another materials, another processes. As well, classifications may have different numbers of classes.

Three points may be noted concerning the philosophy of hazard related classifications. First, a simple classification directly or indirectly involving the geomorphology of the region is desirable. It should be easy to use and easy to explain. Complex classifications should be avoided, including those resulting from numerical taxonomic principles. Secondly, unless a very big database is available, it is not valid statistically to create a large number of classes. Lastly, if most of a study area falls into classes rated as at moderate risk, a manager will probably feel that the classification does not serves adequately as a planning tool. Thus when creating a classification, the combinations of factors and cutoff values (e.g. slope breaks) should be sought which best demarcate both those areas most subject to failure and those most likely to be stable. If this is done well, the number of hectares in the intermediate classes with moderate ratings should be reduced.

Definition of Stability Classes

Using the stability statistics defined above, it becomes possible to group the terrain classes into categories of a stability classification. Specifically, some of the classes of a terrain classification may be grouped together if their respective stability statistics are interpreted similarly. This leads to the notion of a lookup table. As applicable here, a lookup table consists of two rows of numbers, the top row showing the classes of a terrain classification and the bottom row providing the corresponding classes of the associated stability classification. For example, twelve arbitrarily numbered terrain classes may be lumped into four stability classes where the likelihood of post-logging failure for class 1 is minimal and that for class 4 is high. Another terrain classification with eight classes may be similarly grouped. With such an approach, a terrain classification can be transformed into a stability classification more directly useable by forest managers.

A comparison of the stability implications of two quite different terrain classifications can be most easily made: (i), if the classes of each are first assigned to stability classifications; (ii), if the two resulting stability classifications have the same number of classes; and (iii), if the classes of one stability classification correspond to those of the other in terms of management connotations.

In the present case study three stability classifications are created from three terrain classifications. In all three cases the stability classes are treated as equivalent in the context of the terms 'low', 'low to moderate', 'moderate', and 'high' sensitivity to failure following clearcutting. For each stability classification, class membership of a given terain class is based on the terrain class value of Rfa(i), the ratio of failures to hectares:

```
Stability Class 1:              Rfa(i) < 0.01 - 'low'
Stability Class 2: 0.01 >= Rfa(i) < 0.05 - 'low to moderate'
Stability Class 3: 0.05 >= Rfa(i) < 0.10 - 'moderate'
Stability Class 4: 0.10 >= Rfa(i)        - 'high'
```

These numerical values lead to a rough correspondence between the terrain classifications and stability ratings traditionally applied on the west coast of Vancouver Island and those defined in the present study. If those polygons with slope angles < 20° were included in the study, either they could be placed in stability class 1 or they could be grouped alone in a newly defined stability class 0 rated as having a very low likelihood of failure following clearcutting.

Numerical Comparisons of Different Classifications

Landscape areas can be categorized into stability classes first by one scheme and then by another. The results can be compared to ascertain the degree of correspondence between the classifications. This comparison is best represented by constructing a matrix, M, of order g by g with elements x(i,j), where g is the number of stability classes. Each element equals the number of polygons which are placed in stability class i by one classification and in stability class j by the other classification. The sum of the main diagonal elements of the matrix, x(1,1)+x(2,2)+...+x(n,n), divided by the total number of observations, m, defines p, the proportion of the observations which are classed the same by both classifications. Where the two classifications are completely equivalent, p equals one and all x(i,j) with i not equal to j are zero.

Use of M and p to assess correspondence is not entirely satisfactory. The matrix elements represent frequencies of occurence of the terrain polygons; consequently, the comparison of the classifications is biased toward those classes with higher frequencies. This may be reasonable in the study area, but other locations may have quite different class percentages. Additionally, the unequal weighting of the classes makes the main diagonal elements difficult to interpret. To redress these problems it is possible to 'normalize' the matrix such that the sum of any row or column is set equal to the same value. In the case at hand the value is chosen as m/g, ensuring that the sum of all x'(i,j) elements in M', the new matrix, is m. The proportion of identically classed observations, p', is the best measure of correspondence where all classes are considered equally important. A direct comparison of an individual class i can be similarly defined by dividing the main diagonal element x'(i,i) by m/g, its value if the correspondence for that class were perfect. These class proportions are identified as pi', where i ranges from 1 to g.

Using an iterative proportional fitting technique (Bishop, et al. 1975), the normalization procedure converges to a unique set of maximum likelihood estimates (Fienberg 1970). Theoretically it is assumed that all elements of the matrix may have non-zero values. In the present case this may not be true because the terrain class definitions may assure that certain elements must be zero. The procedure has been changed slightly to partially compensate for this. As used here, the procedure begins by adding 0.5 to all elements in M with one major exception. The addition is not performed on those elements of rows and columns associated with a perfect correspondence; that is, if all observations of a given class i for the two classifications fall on the main

diagonal, the elements x(1,i) to x(g,i) and x(i,1) to x(i,g) are not changed. This exception was put into place in order to prevent any alteration to the results where class i in the two classifications has identical or nearly identical definitions in terms of the polygon terrain attributes. The iterations commence with the calculation of the row marginal sums. The g sums are divided into m/g, producing g quotients. The resulting scalar for each row is multiplied against the matrix elements of that row. Next the column marginal sums are determined and in turn m/g is divided by each of them. These g quotients are then multiplied against each matrix element of the corresponding column. The iteration is completed by comparing the row and column marginal sums to m/g. If any differ from m/g by more than some critical value, another iteration proceeds. Should all the deviations be less than or equal to the critical value, the procedure stops. In the present study the critical value is set at 0.05.

Although the various p statistics are meaningful by themselves, it would be helpful if their variability were known. For example, at the 95% level of confidence what are their lowest expected values? Because classification data are multinomially distributed, the binomial distribution theory may be applied. For large sample sizes the confidence intervals for the proportions can be estimated with reference to the standard normal curve. This technique is applied to p and p'. The corresponding true values of the proportions, P and P', are bounded by (1-alpha)*100% confidence intervals (with alpha the level of significance):

(5)
$$p - z*SQR(p(1-p)/m) - 1/(2m) < P < p + z*SQR(p(1-p)/m) + 1/(2m)$$

(6)
$$p' - z*SQR(p'(1-p')/m) - 1/(2m) < P' < p' + z*SQR(p'(1-p')/m) + 1/(2m)$$

where SQR signifies the square root and z is the value of the gaussian curve leaving an area of alpha/2 to the right (Snedecor and Cochran 1967). The square root term is the standard deviation and 1/(2m) is a correction for continuity which improves the approximation to the normal curve. At the 95% confidence interval z is 1.96. For relatively small sample sizes (say under 30) the normal approximation may lead to under or over estimates of both confidence limits if the proportion is well below or above 0.5, respectively. For this reason the 95% lower and upper bounds of the pi' statistics were assessed using a table of confidence intervals for proportions (Table 41, Pearson and Hartley 1966). Because the bounds for all classes are based on an assumed sample size of m/g, they should be viewed as general guidelines only.

Results & Discussion - Classification Definitions

A simple database of the 168 polygons was constructed using a microcomputer based spreadsheet program. The advantage of using an interactive spreadsheet program is that different assumptions or scenarios can be easily checked. For example, if polygons with till are assumed to be more prone to post-logging failure on steeper slopes, what definition should be applied to the term 'steeper'? There are many ways to determine a reasonable answer. With a spreadsheet it becomes simple to try various answers, such as $> 30°$ or $> 35°$, and then to examine the resulting stability statistics for the classes so affected. With a powerful program and a microcomputer with enough memory, this becomes an efficient way to develop class definitions.

The variables entered into the spreadsheet for each polygon include: (i) dominant surficial material, (ii) whether or not the hillslope is benchy or irregular, (iii) presence or absence of gullies, (iv)presence or absence of natural failures, (v) average slope angle in degrees, (vi) average aspect in degrees, (vii) polygon area, and (viii) the number of presumed logging induced, clearcut failures. The classifications are based on the first six variables only; the last two are required to produce the failure related statistics (Eq. 1 through 4).

The choice of variables (i) through (vi) each involved one or more major assumptions. Certain materials, such as till on steep slopes, are assumed to be comparatively more prone to failure. The presence of gullies or of natural failures suggests a potentially greater sensitivity to disturbances. Benchy or irregular slopes, or slopes with a significant proportion of bedrock outcropping are assumed to be more stable. Steeper slopes generally are less stable. If significant local rainshadow effects exist, east facing slopes in the study area may be less failure prone. All of this reasoning is quite sound geomorphically. Consequently, should the stability statistics determined from any derived classification follow expected trends, it is likely that the results are truly meaningful and not simply due to chance.

For the first classification the term 'remote sensing' may be applied. All of the factors involved can be determined by examination of aerial photographs and topographic maps. More sophisticated techniques such as image processing and analysis of digital topographic models might also be used successfully. Each polygon is placed in one of six terrain classes as defined on Table 1.

Because of the seqential nature of the logic in the class criteria, it may be worthwhile to clarify these definitions. Class 1 contains those polygons dominated by bedrock outcrops. Class 2 implies the presence of natural failures and materials other than bedrock as dominant. Class 3 involves east facing areas with no natural failures and with bedrock not dominant. In class 4 are west facing areas with slopes >= 30° and with gullies, but without natural failures or dominant bedrock. Class 5 includes west facing areas with slopes >= 30° and without gullies, natural failures, or dominant bedrock. In class 6 are west facing areas with slopes < 30° and without gullies, natural failures, or dominant bedrock.

The Pf(i), Rfa(i), and Rfpf(i) stability statistics (Table 2) follow similar trends with higher values of one generally indicative of higher values of the others. Based on the values of Rfa(i), a lookup table can be constructed relating terrain classes to stability classes (Table 3). It can be seen that bedrock dominated polygons and east facing polygons with no natural failures are evaluated as the most stable. Polygons with natural failures or with steep (>= 30°), gullied slopes are considered as most prone to failure.

The second terrain classification ignores aspect but does take into account the different types of surficial materials. Consequently, application of this 'geomorphic' classification would demand a greater degree of groundtruthing than does the previous, 'remote sensing' classification. Seven classes are defined (Table 4). The same kind of sequential logic as used previously is employed here. Classes 1 through 6 are clearly defined on Table 4. Class 7 is filled primarily with bedrock dominated polygons. The stability statistics are displayed on Table 5. These seven terain classes can be grouped into four risk categories as before (Table 6). Note that the range of stability statistics for each stability class here is similar but not identical to that for the first classification.

A review of Tables 4, 5, and 6 shows that the following types of polygons are likely to be most stable: bedrock dominated polygons, polygons on benchy or irregular slopes with slope angles <= 40°, polygons dominated by morainal or fluvioglacial deposits with slope angles <= 30°, and colluvial dominated polygons with slopes <= 35°. At the other extreme of the stability spectrum are polygons with natural failures or with gullies and slope angles > 25°.

Classification 3 (Tables 7, 8, and 9) represents a combination of the other two classifications and the term 'geomorphic + aspect' may be applied. The definitions of the classes are nearly the same as those for classification

2; the only difference is that classes 2 through 6 are all restricted to west facing slopes. The significance of this is that, as with the first classification, all east facing polygons without natural failures are also rated as having low sensitivity to post-logging failure.

Results & Discussion - Classification Comparisons

The three resulting stability classifications and their respective classes can be compared to one another. Table 10 displays the matrix showing class assignments of the 168 polygons based on classifications 1 and 2. On Table 11 is shown the normalized matrix with the sums of all rows and columns set to 42. The p and p' proportions for the two matrices are virtually the same at 0.73 and 0.72, respectively (Table 12). Using the 95% confidence limits for either statistic, it follows that an approach based strictly on what can be gleaned by remote sensing may range from approximately 0.65 to 0.80 equivalence compared to a more traditional geomorphic approach. Nevertheless, the practical significance of such a high level of disparity depends in large measure on where the major disagreemnts lie. An examination of the individual class statistics, p1' through p4', shows that the level of agreement of the most sensitive class, class 4, is high with a mean value of 0.92 and a 95% confidence interval of 0.79 to 0.98. At the other extreme the estimated mean for class 1 is 0.59, ranging from 0.43 to 0.74. The statistics for the two middle classes fall between those of classes 1 and 4. Thus, although the classifications appear rather different overall, their treatment of the most failure prone areas is quite similar.

Results of the comparison of classifications 1 and 3 are provided on tables 13, 14 and 15. Here the p and p' statistics are 0.86 and 0.90, the first varying from 0.80 to 0.91 and the second from 0.85 to 0.95. By adding the variable aspect to the 'geomorphic' class criteria, the overall similarity to the 'remote sensing' system, is greatly increased. In fact, there is now perfect correspondence (p4'=1) between classifications 1 and 3 for class 4. A careful examination of the class definitions on Tables 1, 3, 4 and 6 shows that the terrain characteristics for stability class 4 for the two classifications are nearly identical.

Classifications 2 and 3 are compared on tables 16, 17 and 18. The statistics p and p' and p4' are 0.87, 0.92, and 0.93, respectively, indicating a high degree of correspondence between the classifications and specifically between the two versions of stability class 4.

These comparisons provide insight into the relationships among the classifications and their classes; however, it still is not clear which terrain classification is preferable. One might be inclined toward the third one because it contains the greatest degree of definition of the three. A more practical reason involves the area comparisons given on Table 19. Here it can be seen that of the three classifications 3 has the highest percentage (41%) in stability class 1, the lowest (38%) in classes 2 and 3 when combined, and the lowest (22%) as well in class 4. (Note that the percentages on Table 19 would all be substantially lower if polygons with slope angles < 20° had not been excluded). For the study area at least, terrain classification 3 seems to do the best at isolating sensitive areas. On the other hand, the first, 'remote sensing' classification would be the cheapest to apply if an appropriate terrain database were not available for the area in question. Use of this approach might be particularly justified should quick results of large areas be required for general plannng and assessment purposes.

Conclusions

Using statistically oriented quantitative techniques, it should be possible to provide extensive stability class mapping over large portions of British Columbia. A series of logged study areas scattered throughout the major physiographic regions could be analyzed in detail; for each region various proposed stability classifications could then be examined and compared. Next, the results could be extrapolated to unlogged areas throughout each region. The databases might include geomorphic and topographic attributes, and potentially, climate data and bedrock geology. Alternatively, remote sensing techniques coupled with digital topographic models might lead to adequate results where detailed field mapping is not available. To make the final products of any such studies more applicable to objective forest planning, efforts should be made to combine them with information on expected landslide magnitude and routing.

References

Bishop, Y., S. Fienberg, and P. Holland. 1975. Discrete Multivariate Analysis: Theory and Practice. MIT Press, Cambridge, Mass.

Bourgeois, W.W. 1974. Alliford Bay area geotechnic inventory. Land Use Planning Advisory Team, Woodlands Sevices, MacMillan Bloedel Ltd., Nanaimo, B.C.

Canada Soil Survey Committee, Subcommittee on Soil Classificaton. 1978. The Canadian System of Soil Classification. Agriculture Canada Publ. 1646. Supply and Services Canada, Ottawa.

Chatwin, S.C. and T.P. Rollerson. 1984. Landslide study TFL 39, Block 6. Land Use Planning Advisory Team, Woodlands Services Division, MacMillan Bloedel Ltd., Nanaimo, B.C.

Environment and Land Use Committee Secretariat. 1976. Terrain classification system. British Columbia Ministry of Environment, Victoria, B.C.

Fienberg S. 1970. An iterative procedure for estimation in contingency tables. Annals of Mathematical Statistics. Vol. 41B, pp.907-917.

Holland, S.S. 1976. Landforms of British Columbia, a physiographic outline. Bulletin 48. British Columbia Ministry of Mines and Petroleum Resources, Victoria, B.C.

Krajina, V.J. 1969/70. Ecology of forest trees in British Columbia. Ecology of Western North America. Vol. 2, pp.1-147.

Pearson, E.S. and H.O. Hartley. 1966. Biometrika Tables for Statisticians, Volume 1. Cambridge Univ. Press, Cambridge, England.

Rollerson, T.P. 1984. Landslide study TFL 44. Land Use Planning Advisory Team, Woodlands Services Division, MacMillan Bloedel Ltd., Nanaimo, B.C.

Ryder, J.M. and D.E. Howes. 1984. Terrain Information, A User's Guide to Terrain Maps in British Columbia. British Columbia Ministry of Environment, Victoria, B.C.

Snedecor and Cochran. 1967. Statistical Methods, 3rd Ed. Iowa State Univ. Press, Ames, Iowa.

Terzaghi, K. and R. Peck. 1967. Soil Mechanics in Engineering Practice, 2nd, Ed. Wiley, New York.

Tsukamoto, Y., T. Ohata, and H. Noguchi. 1982. Hydrological and geomorphological studies of ebris slides on forested hillslopes in Japan. In Recent Developments in the Explanation and Prediction of Erosion and Sediment Yield (Proccedings of the Exter Symposium, July 1982). I.A.H.S. Publ. No. 137.

Table 1: Class Criteria for Terrain Classification 1

Class 1: dominated by bedrock.
Class 2: not class 1;
natural failures present.
Class 3: not class 1 or 2;
aspect <= 180° (east facing).
Class 4: not class 1, 2 or 3;
gullies present;
slope angle >= 30°.
Class 5: not class 1, 2, 3 or 4;
slope angle >=30°.
Class 6: not class 1, 2, 3, 4 or 5.

Note that the classification is restricted to those polygons with slope angles >= 20°.

Table 2: Stability Statistics for Terrain Classification 1

Class	#	Pf(i)	Rfa(i)	Rfpf(i)	Pata(i)
1	15	0.000	0.000	N/A*	9%
2	24	0.750	0.319	2.78	14%
3	39	0.026	0.004	1.00	23%
4	9	0.444	0.320	2.75	5%
5	15	0.200	0.077	1.67	9%
6	66	0.121	0.030	1.25	39%

* N/A implies division by zero.
# refers to the number of polygons in the class.

Table 3: Stability Classification 1 Assignments as related to Terrain Classification 1

Terrain Class:	1	2	3	4	5	6
Stability Class:	1	4	1	4	3	2

Table 4: Class Criteria for Terrain Classification 2

Class 1: natural failures present;
bedrock not dominant.
Class 2: not class 1;
bedrock not dominant;
gullies present;
slope angle > 25°.
Class 3: not class 1 or 2;
bedrock not dominant;
slope morphology is benchy or irregular;
slope angle <= 40°.
Class 4: not class 1, 2 or 3;
morainal* or fluvioglacial dominant;
slope angle <= 30°.
Class 5: not class 1, 2 or 3;
colluvial dominant;
slope angle <= 35°.
Class 6: not class 1, 2 or 3;
morainal* or fluviolglacial dominant and
slope angle > 30°, or
colluvial dominant and
slope angle > 35°.
Class 7: not class 1, 2, 3, 4, 5, or 6.

* As used here morainal may be either till or a veneer of colluvium over till.
Note that the classification is restricted to those polygons with slope angles >= 20°.

Table 5: Stability Statistics for Terrain Classification 2

Class	#	Pf(i)	Rfa(i)	Rfpf(i)	Pata(i)
1	24	0.750	0.319	2.78	18%
2	15	0.333	0.189	2.40	7%
3	15	0.000	0.000	N/A*	10%
4	60	0.067	0.017	1.25	33%
5	12	0.000	0.000	N/A*	11%
6	25	0.280	0.076	1.43	15%
7	17	0.000	0.000	N/A*	7%

* N/A implies division by zero.
# refers to the number of polygons in the class.

Table 6: Stability Classification 2 Assignments as related to Terrain Classification 2

Terrain Class:	1	2	3	4	5	6	7
Stability Class:	4	4	1	2	1	3	1

Table 7: Class Criteria for Terrain Classification 3

Class 1: natural failures present;
bedrock not dominant.
Class 2: not class 1;
bedrock not dominant;
gullies present;
slope angle > 25°;
aspect > 180°.
Class 3: not class 1 or 2;
bedrock not dominant;
slope morphology is benchy or irregular;
slope angle <= 40°;
aspect > 180°.
Class 4: not class 1, 2 or 3;
morainal* or fluvioglacial dominant;
slope angle <= 30°;
aspect > 180°.
Class 5: not class 1, 2 or 3;
colluvial dominant;
slope angle <= 35°;
aspect > 180°.
Class 6: not class 1, 2 or 3;
morainal* or fluviolglacial dominant and
slope angle > 30°, or
colluvial dominant and
slope angle > 35°;
aspect > 180°.
Class 7: not class 1, 2, 3, 4, 5, or 6.

* As used here morainal may be either till or a veneer of colluvium over till.
Note that the classification is restricted to those polygons with slope angles >= 20°.

Table 8: Stability Statistics for Terrain Classification 3

Class	#	Pf(i)	Rfa(i)	Rfpf(i)	Pata(i)
1	24	0.750	0.319	2.78	18%
2	9	0.444	0.320	2.75	4%
3	6	0.000	0.000	N/A*	4%
4	47	0.085	0.022	1.25	26%
5	5	0.000	0.000	N/A*	3%
6	22	0.318	0.090	1.43	12%
7	55	0.018	0.003	1.00	34%

* N/A implies division by zero.
# refers to the number of polygons in the class.

Table 9: Stability Classification 3 Assignments as related to Terrain Classification 3

Terrain Class:	1	2	3	4	5	6	7
Stability Class:	4	4	1	2	1	3	1

Table 10: Comparison of Class Membership of Stability Classifications 1 and 2

Stability Classification 2	Stability Classif. 1				marginal sums
	1	2	3	4	
1	32	7	5	0	44
2	13	47	0	0	60
3	3	12	10	0	25
4	6	0	0	33	39
marginal sums:	54	66	15	33	

Table 11: Comparison of Stability Classifications 1 and 2 following Matrix Normalizaton

Stability Classification 2	Stability Classif. 1				marginal sums
	1	2	3	4	
1	24.9	4.3	11.8	1.0	42.0
2	11.0	29.7	1.2	1.1	42.0
3	3.4	8.9	28.4	1.3	42.0
4	2.7	0.2	0.6	38.5	42.0
marginal sums:	42.0	42.0	42.0	42.0	

(Note: on this and subsequent tables, rounding of matrix values may lead to minor discrepancies with marginal sums and the estimates for p' and p1' through p4'.

Table 12: Correspondence Statistics for Classifications 1 and 2

	p	p'	p1'	p2'	p3'	p4'
Mean	0.73	0.72	0.59	0.68	0.68	0.92
95% Lower Bound	0.66	0.65	0.43	0.52	0.52	0.79
95% Upper Bound	0.80	0.79	0.74	0.82	0.82	0.98

Table 13: Comparison of Class Membership of Stability Classifications 1 and 3

Stability Classification 3	Stability Classif. 1				marginal sums
	1	2	3	4	
1	54	7	5	0	66
2	0	47	0	0	47
3	0	12	10	0	22
4	0	0	0	33	33
marginal sums:	54	66	15	33	

Table 14: Comparison of Stability Classifications 1 and 3 following Matrix Normalizaton

Stability Classification 3	Stability Classif. 1				marginal sums
	1	2	3	4	
1	37.5	0.7	3.0	0.0	42.0
2	2.9	36.1	3.0	0.0	42.0
3	1.6	5.3	35.1	0.0	42.0
4	0.0	0.0	0.0	42.0	42.0
marginal sums:	42.0	42.0	42.0	42.0	

Table 15: Correspondence Statistics for Classifications 1 and 3

	p	p'	p1'	p2'	p3'	p4'
Mean	0.86	0.90	0.89	0.86	0.84	1.00
95% Lower Bound	0.80	0.85	0.76	0.72	0.69	0.92
95% Upper Bound	0.91	0.95	0.97	0.95	0.93	1.00

Table 16: Comparison of Class Membership of Stability Classifications 2 and 3

Stability Classification 3	Stability Classif. 2				marginal sums
	1	2	3	4	
1	44	13	3	6	66
2	0	47	0	0	47
3	0	0	22	0	22
4	0	0	0	33	33
marginal sums:	44	60	25	39	

Table 17: Comparison of Stability Classifications 2 and 3 following Matrix Normalizaton

Stability Classification 2	Stability Classif. 1				marginal sums
	1	2	3	4	
1	36.5	2.5	1.3	1.8	42.0
2	1.8	38.7	0.8	0.6	42.0
3	1.9	0.4	39.1	0.6	42.0
4	1.8	0.4	0.8	39.0	42.0
marginal sums:	42.0	42.0	42.0	42.0	

Table 18: Correspondence Statistics for Classifications 2 and 3

	p	p'	p1'	p2'	p3'	p4'
Mean	0.87	0.91	0.87	0.92	0.93	0.93
95% Lower Bound	0.82	0.87	0.72	0.79	0.81	0.81
95% Upper Bound	0.92	0.96	0.96	0.98	0.98	0.98

Table 19: Area Comparisons of the Three Stability Classifications

Stability Class	Stability Classification 1	2	3
1	34%	28%	41%
2	38%	33%	26%
3	7%	15%	12%
4	22%	25%	22%

Values are based on the percentage of the total study area occupied by each class, for each classification.

Present and Future Trends in Quantitative Image Analysis and its Implications to Soil Science

Robert J. Woodham[1]
Departments of Forest Resources Management and Computer Science
University of British Columbia
Vancouver, BC

Introduction

This paper describes present and future trends in quantitative image analysis and provides a selected reference list for further reading. The author is not a Soil Scientist and cannot make assertions regarding implications to Soil Science. Nevertheless, it is hoped that specialists in the field can draw their own conclusions from the material presented. The references given have been chosen, so far as is possible, to be accessible to the non-specialist. They, in turn, provide additional pointers to the scientific literature.

Seven trends are identified. The first six are technical in nature while the seventh is essentially political. The seven trends are listed below and elaborated upon in the sections that follow:

- Quantitative image analysis means computer-based image analysis.
- Satellite imagery can be geocoded on an operational basis.
- Satellite imagery is being integrated with other geocoded information sources.
- Quantitative methods depend increasingly on physical models of image formation.
- There is a current fascination with the technology of Artificial Intelligence expert systems.
- Experts systems for image analysis must identify the levels of representation required and must specify the constraints that operate both within and between levels.
- Funding sources for research and development of remote sensing and geographic information systems are changing.

Quantitative Image Analysis

In remote sensing, digital image analysis gained prominence with the first Landsat satellite launched in 1972. The Landsat multispectral scanner(MSS) is a digital sensor. That is, measurements of scene radiance are quantised and converted into numbers onboard the satellite. Images are transmitted to ground receiving stations as a stream of numbers. Some form of digital image processing[6] is therefore required, if only to write the digital data onto film for subsequent human interpretation.

Clearly, an opportunity was created for automatic digital image analysis. The view that persisted, however, was that while it can be appropriate to use digital image

[1] R.J. Woodham is a Fellow of the Canadian Institute for Advanced Research.

analysis on images that are digital to begin with, manual photo-interpretation is preferable for imagery obtained by traditional aerial photography.

This view is changing. One reason is that it is now routinely possible to convert any film product to a digital image without loss of information. For example, the Optronics film scanner of the UBC Laboratory for Computational Vision can scan film at a grid spacing of 12.5 μm per digital picture element. This is equivalent to 40 lines/mm, a resolving power comparable to that of many aerial films. Thus, digital image analysis is not inherently working with an inferior product.

Of course, demonstrating that there is no loss of information between film and digital image does not imply that there exist computer systems that can interpret all of this information. Results of quantitative image analysis based on spectral classification are still rather crude compared to the skilled photo-interpreter[8]. Nevertheless, it is clear that quantitative studies demand a precision and speed attainable only with computer-based systems. A variety of research is underway to provide computer-based systems with the additional knowledge representations and contextual rules required to correctly interpret digital data at the level of a skilled photo-interpreter.

As a practical matter, Canada's resource-based economy and vast, often inaccessible, land and water bodies make automatic remote sensing the only viable technology for resource management. In remote sensing, quantitative image analysis means computer-based image analysis.

Geocoded Image Data

Satellite images, like aerial photographs, cannot be overlayed directly onto a map. Digital processing can be used to rectify a satellite image. That is, the image can be geometrically warped into a standard coordinate frame, such as the Universal Transverse Mercator (UTM) projection used in Canadian National Topographic System (NTS) maps. Once an image has been rectified to a standard coordinate frame, it is said to be geocoded.

Until recently, rectification was a rather tedious operation requiring manual attention and a large amount of computer time. Now, the process is sufficiently automated and supported by special purpose hardware that geocoded satellite imagery is available on a operational basis. In Canada, geocoded Landsat MSS imagery is produced using the Digital Image Correction System (DICS) at the Canada Centre for Remote Sensing (CCRS). Landsat Thematic Mapper (TM) imagery, as well as imagery from the forthcoming French SPOT satellite, will be geocoded using the Multi-Observational Satellite Image Correction System (MOSAICS), under development for CCRS by MacDonald, Dettwiler and Associates, Ltd. (MDA).

Geocoded images have several advantages. Images from different dates can be directly combined as a means of change detection. Images from different sensors also can be combined to produce novel image products. As one example, Landsat/Seasat composite images have been generated[13]. The composite combines radar data from Seasat that is sensitive to surface roughness with multispectral data from Landsat that is sensitive to ground cover. Finally and most importantly, geocoded images also can be combined with other geocoded information such as topographic maps, forest cover maps

and soil maps to form an integrated resource management system.

Integrating Geocoded Data Sources

Two disciplines, Remote Sensing and Geographic Information Systems, are both mature fields that have developed more or less independently. The challenge now is to integrate image analysis with other geographic information to form an effective resource management system. Geocoding to a common coordinate frame is a start but much work needs to be done.

Digital image analysis deals with image data represented on a regular grid, called a raster. Computerised mapping systems typically deal with line data represented as vectors or polygons. Some problems of conversion between representations are straightforward. For example, one can convert a topographic map, represented by contour lines, to a gridded array of elevations, called a digital terrain model (DTM). DTM's have been integrated into remote sensing image analysis for both the geometric rectification and radiometric correction of satellite imagery. Other problems of conversion can be more difficult because local topological relationships must be preserved. For example, conversion of vectors for a road and a river running side-by-side to raster form would lose connectivity and adjacency information if the result were an intermingling of isolated "road" and "river" raster elements.

In an integrated system, image data is used to verify and to update map information. At the same time, map information is useful in image analysis because it identifies spatial relationships and provides appropriate local context for interpretation. Some examples from research suggest what is possible[7,11,10,4], although these ideas have yet to be incorporated into operational systems.

A map contains a lot of information. Some information is explicit and can be accessed directly. Other information is implicit and must be inferred from what is represented explicitly. Automatic map interpretation is a problem in its own right that has received some attention[4].

The major thrust of current research is to integrate remote sensing and geographic information systems. For example, the Canada Centre for Remote Sensing and the BC Ministry of Forests are collaborating to combine CCRS's image analysis system with the Ministry's Interactive Graphics Design System (IGDS) for forest cover mapping and inventory.

Physical Models of Image Formation

Computational vision is the study of computational systems that interpret images; that is, they produce descriptions of a world from images of that world[1,2]. The central concern is the design and implementation of effective algorithms that represent and exploit knowledge of the world and knowledge of how images are formed. This knowledge includes properties of sensors, laws of physical optics and information about possible configurations in the world.

The brightness at each point in a remotely sensed image is determined by physical properties of the corresponding ground point. These properties include: the sun and sky

illumination, the reflectance characteristics of the surface material and the slope and aspect of the ground relative to the sensor position and the direction of illumination. Brightness is also influenced by absorption properties of the atmosphere. Absorption properties, in turn, depend upon elevation. Thus, brightness encodes a great deal of information about the scene. Decoding brightness measurements requires a physical model of how the world determines what we see. Progress has been made to develop models that relate topography, ground cover, atmosphere, illumination and viewer position[9,14]. With these models, DTM's are used to account for the effects of topography in order to better delineate ground cover.

Even under the most favourable circumstances, image interpretation can be locally ambiguous. In such situations, information about possible configurations in the world can resolve a local ambiguity by appealing to a more global context[7,4].

Artificial Intelligence and Expert Systems

Artificial Intelligence (AI), once the avant-garde of Computer Science, has suddenly become a mainstream activity[12]. This is in part due to the emergence of commercially successful "expert systems" and in part due to major investments being made in Japan[3], and elsewhere, to develop "knowledge-based systems". Recent articles in *Business Week*[2] and *Fortune*[3] examine this AI technology from a business point of view.

There is a fascination with AI expert systems. Current expert systems are simple rule-based systems[5]. That is, knowledge in a certain domain is expressed as a set of rules. Given a particular set of initial facts, the system invokes whatever rules apply to deduce new facts or to take required actions. This process iterates until a desired goal has been achieved. For example, a remote sensing system might have a rule of the form, "If there is a river from a point A to a point B and if point A is higher in elevation than point B then the river flows from A to B.". This rule encodes the knowledge that water flows downhill. It might be useful in a remote sensing system whose goal was to identify distinct watershed areas.

One analogy is to imagine a senior university professor nearing retirement age. One way a professor passes on expertise is by direct contact with students and colleagues. This is a form of apprenticeship. To reach a wider audience, the professor can consider writing the definitive textbook in the field. Textbook knowledge, however, suffers from not being readily applicable. A more dynamic form of knowledge transfer would be ideal. One can think of AI expert systems as providing just such a new tool for knowledge transfer. An expert, or collection of experts, provide the rules in a given formalism. Computer systems apply the rules directly to actual situations so that the consequences are made immediately clear. The experts can add new rules to cover unanticipated situations. Similarly, existing rules can be altered, if needed, to restrict their domain of applicability.

Expert systems do not create sense out of nonsense. Rather, they provide a sometimes useful way to encode existing knowledge into computer systems. Expert systems

[2] "Artificial intelligence is here", *Business Week*, July 9, 1984.

[3] "Thinking machines", (a three part series), *Fortune*, May 17, 31 and June 14, 1984.

for image analysis remain elusive, not because it is difficult to write down rules but because it is first necessary to determine representations in which the rules can be applied.

Expert Systems for Image Analysis

The long term goal of remote sensing research is to produce expert systems for image analysis and natural resources management. Two ideas from AI are of central concern. First, one must define the different levels of representation to be used at different stages of a computation. Second, the constraints (rules) that apply both within each level and when moving from one level to another must be identified.

These ideas can be illustrated by a sample problem I often pose to students, "What would it take to write a computer program that, given an aerial photograph of Vancouver, could locate all the golf courses?" The problem is difficult. One cannot go directly from raster elements in a digital image to golf courses. Multiple levels of representation are required. Fairways appear as elongated blobs, usually in groups of nine. There is a parking lot and a club house nearby. Usually, there are sand traps and water hazards. There must be a way to walk from each green to the next tee. Usually, pathways are provided for electric golf carts. The course must be accessible by road from the rest of the city. Certainly, some golf courses may violate one or more of these rules but that is not the point. The point is that to apply these rules descriptions must be computed that identify regions including properties of colour, shape and size. Descriptions also must be computed that identify relationships between regions.

The task of computational vision is to define the levels of representation required and to identify the constraints that operate both on and between the descriptions that can be computed at each level. Expert systems will not function simply as a post-processor to be applied once existing image analysis techniques have completed their work.

Funding Remote Sensing and Geographic Information Systems

In both Canada and the U.S., funding for satellite-based remote sensing has been included as part of each nation's space program. It is evident from the trends identified above that new initiatives in remote sensing and geographic information systems relate more to ground-based systems than to space technology. Indications are that major funding for these initiatives will not be justifiable as part of a space budget.

At the same time, Canada is formulating a national plan to respond to "fifth generation" projects underway in Japan and elsewhere. This plan must take into account application areas of importance to Canada. It seems likely that natural resources management will be one area of application specifically targeted in any national plan. The Canadian Advisory Committee on Remote Sensing (CACRS) has established an Image Analysis Systems and Artificial Intelligence Working Group to make recommendations concerning the implications of Artificial Intelligence to remote sensing and geographic information systems. BC representatives on this Working Group are: Frank Hegyi, Ministry of Forests; John MacDonald, MacDonald Dettwiler and Associates, Ltd; and Bob Woodham, University of British Columbia.

As one member of the Working Group, I encourage all interested parties to make their needs and views known. To those of us concerned with natural resource management, it is self-evident that this is an area of utmost importance to Canada. Nevertheless, much work will be required to achieve a level of funding commensurate with that importance.

References

1. Barrow, H.G. & J.M. Tenenbaum (1981), "Computational vision", *Proceedings IEEE* (69)572-595.
2. Brady, M. (1982), "Computational approaches to image understanding", *ACM Computing Surveys* (14)3-72.
3. Feigenbaum, E.A. & P. McCorduck (1983), *The Fifth Generation*, Addison-Wesley.
4. Havens, W.S. & A.K. Mackworth (1983), "Representing knowledge of the visual world", *IEEE Computer* (16)90-96.
5. Hayes-Roth, F., D. Waterman & D. Lenat (1983), *Building Expert Systems*, Addison-Wesley.
6. Moik, J.G. (1980), "Digital Processing of Remotely Sensed Images", NASA SP-431, US Government Printing Office.
7. Starr, D.W. & A.K. Mackworth (1978), "Exploiting spectral, spatial and semantics constraints in the segmentation of Landsat images", *Canadian Journal of Remote Sensing* (4)101-107.
8. Swain, P.H. & S.M. Davis (1973), *Remote Sensing: The Quantitative Approach*, McGraw-Hill.
9. Teillet, P.M., B. Guindon & D.G. Goodenough (1982), "On the slope-aspect correction of multispectral scanner data", *Canadian Journal of Remote Sensing* (8)84-106.
10. Tenenbaum, J.M., H.G. Barrow, R.C. Bolles, M.A. Fischler & H.C. Wolf (1979), "Map-guided interpretation of remotely-sensed imagery", *Proc. IEEE Computer Society Conf. on Pattern Recognition and Image Processing*, pp 610-617.
11. Tenenbaum, J.M., M.A. Fischler & H.C. Wolf (1978), "A scene-analysis approach to remote sensing", TN-173, Artificial Intelligence Center, Stanford Research Institute, Menlo Park, CA.
12. Winston, P.H. & K.A. Prendergast (1984), *The AI Business: The Commercial Uses of Artificial Intelligence*, MIT Press.
13. Wong, F. (1984), "A unified approach to the geometric rectification of remotely sensed imagery", TR-84-6, UBC Dept. of Computer Science, Vancouver, BC.
14. Woodham, R. & T.K. Lee (1984), "Photometric method for radiometric correction of multispectral scanner data", *Canadian Journal of Remote Sensing* (to appear), also available as TR-84-14, UBC Dept. of Computer Science, Vancouver, BC.

NINTH B.C. SOIL SCIENCE WORKSHOP

SESSION FOUR - Tour of Environmental Laboratory,
B.C. Ministry of Environment,
UBC Campus

February 22, 1985 P.M.

L.E. Lowe, Session Chairman

SESSION FOUR - TOUR OF THE ENVIRONMENTAL LABORATORY,
British Columbia Ministry of Environment,
3650, Wesbrook Crescent,
Vancouver, British Columbia.

Approximately 50 Workshop attendees participated in the tour of the Environmental Laboratory of the afternoon of February 22, 1985. Prior to the actual tour, the Laboratory staff described the organization of the laboratory and its' functions as an accredited facility. It provides analytical services for various branches in the Ministry of Environment, other ministries and agencies, as well as services for outside organizations on a fee-for-service basis.

The tour outlined the laboratories' procedure for receiving, recording, preparing and analyzing various kinds of samples and the methods of reporting the computerized results. Described also were the methods employed for maintaining quality control. Also exhibited were the various analytical equipment (much is state-of-the-art). Safety procedures were also described as well as the laboratorys' flexibility to respond to requirements for analyses on an emergency basis.

APPENDICES

APPENDIX 1

NINTH BRITISH COLUMBIA SOIL SCIENCE WORKSHOP

You are invited to the 9th British Columbia Soil Science Workshop!

THEME - The Role of Soil Analysis in Resource Management

WHEN - February 21 and 22, 1985

WHERE - Room 166, MacMillan Building, University of British Columbia, Vancouver, B.C.

REGISTRATION - Anytime during the first day, but preferably in the morning

FEE - Not more than $10, which will provide a copy of the proceedings and cover the cost of postage, coffee and 'goodies'.

The Workshop is being held under the auspices of the B.C. Land Resource Science Lead Committee. It will address the soil analysis needs of the agricultural and forest industries, as well as some other land users. It will also focus on soil analysis from the perspective of the laboratory and discuss methods for dealing with soil variability.

The Workshop program is attached. Please circulate it among your colleagues and friends for widest distribution. If you have any questions, please contact Lawrence Lowe (228-3478, Vancouver), Tim Ballard (228-2300, Vancouver), or myself (860-7393, Kelowna).

Circle February 21 and 22/85 on your calendar now, and plan to attend! I hope to see you there.

H. A. Luttmerding,
Chairman, Organizing Committee.
December 27/84

PROGRAM

9th BRITISH COLUMBIA SOIL SCIENCE WORKSHOP

SESSION ONE - Thursday A.M., Feb 21/85

Session Chairman - G.G. Runka, Land Sense Ltd., Burnaby, B.C.

Topic - The Needs and Expectations of Soil Analysis Users

8:45	- 9:00	Welcome. L. Lavkulich, Chairman, B.C. Land Resource Science Lead Committee
9:00	- 9:30	Laboratory Analyses Applied On and Beyond the Farm. W.A. Herman, Pacific Soil Analysis Inc., Vancouver.
9:30	- 9:55	Horticultural Requirements and Interpretations. B. Mauza, B.C. Ministry of Agriculture and Food, Abbotsford.
9:55	- 10:20	Chemical Data Requirements for Forestry Interpretations. T. Lewis, Consultant, Burnaby, B.C.
10:20	- 10:45	Break
10:45	- 11:10	Chemical Attributes in Making Environmental Interpretations. J. Wiens, B.C. Ministry of Environment, Victoria.
11:10	- 11:35	Chemical Data in Soil Taxonomy. L. Lavkulich, Dept. of Soil Science, U.B.C.
11:35	- 12:00	What Does the Data User Expect of Soil Analysis? Panel consisting of the previous speakers
12:00	- 1:15	Lunch

SESSION TWO - Thursday P.M., Feb 21/85

Session Chairman - W. van Lierop, British Columbia Ministry of Agriculture and Food, Kelowna

Topic - Approaches in Soil Analyses and Interpretations

1:15 - 1:30 Some Possible Approaches to Soil Nitrogen Availability Testing in Field Soils and Soilless Mixes. Michael Rowell, Norwest Soil Research Inc., Langley, B.C.

1:30 - 1:45 Review of Bray's Soil Test Calibration Theory. R. Bertrand, B.C.M.A.F., Cloverdale, B.C.

1:45 - 2:00 Laboratory Determination and Interpretation of Soil Physical Properties. Michael Goldstein, Soilcon Laboratories Ltd., Vancouver, B.C.

2:00 - 2:15 Soil Variability with Respect to Soil Test Values. A.L. van Ryswyk*, John Hall and W. van Lierop, Agriculture Canada, Kamloops, B.C. and B.C.M.A.F., Kelowna, B.C.

2:15 - 2:30 Elemental Analyses Using Inductivily Coupled Plasma - Principles and Horizons. Michael W. Blades. Department of Chemistry, U.B.C., Vancouver, B.C.

2:30 - 2:45 Comparisons Among "Available" Zinc Extractants for Southern Interior Soils. Denise Neilsen*, P. Hoyt and A.F. MacKenzie, McGill University and Agriculture Canada, Summerland, B.C.

2:45 - 3:00 Comparison of the Pipette and Hydrometer Methods for Determining Soil Particle-Size Distribution. Hong Chuah, B.C.M.A.F., Kelowna, B.C.

3:00 - 3:30 Break

3:30 - 3:45 Zinc and Phosphorus Interaction in Apple Seedings Grown in Nutrient Solutions. G.H. Neilsen* and E.J. Hogue, Agriculture Canada, Summerland

3:45 - 4:00 ^{15}N-tracer Methodology in Soil Research. P.C. Pang, Pacific Forest Research Centre, Victoria, B.C.

4:00 - 4:15 Advantages of ^{15}N Techniques in Interpreting Data for Soil Research. C.G. Kowalenko, Agriculture Canada, Agassiz, B.C.

4:15 - 4:30 Comparison of Laboratory Methods for Evaluating Plant-Available Soil Phosphorus. W. van Lierop, B.C.M.A.F., Kelowna, B.C.

SESSION THREE - Friday A.M., Feb 22/85

Session Chairman - Hans Schreier, Dept. of Soil Science, U.B.C.

Topic - How to Deal with Soil Variability

8:40	-	9:00	Soil Variability, does it Invalidate our Interpretations? D. Moon, Agriculture Canada, Vancouver and H. Schreier, Dept. of Soil Science, U.B.C.
9:00	-	9:20	How do Geotechnical Engineers Deal with Soil Variability and Sampling? J. Gadsby, Gadsby Geotechnical Consultants Ltd., Vancouver.
9:20	-	9:50	Present and Future Trends in Soil Fertility Assessments. J. Beaton, Potash and Phosphate Institute, Cochrane, Alberta
9:50	-	10:10	Implications of Soil Variability on Fertilizer Assessments for Crop Production. G. Kowalenko, Agriculture Canada, Agassiz.
10:10	-	10:30	Break
10:30	-	10:50	Strategic Fertilizer Programmes for Individual Farmers in New Zealand. S. Smith, New Zealand Soils Bureau, Dunedin, N.Z.
10:50	-	11:10	Foliar Analysis for Deficiency Diagnosis and Fertilizer Prescription in Forestry. T. Ballard, Dept. of Soil Science, U.B.C.
11:10	-	11:30	Using Probability Assessments in Soil Research. M. Sondheim, Ministry of Environment, Victoria and T. Rollerson, MacMillan Bloedel Ltd., Nanaimo
11:30	-	12:00	Present and Future Trends in Quantitative Image Analysis and its Implications to Soil Science. B. Woodham, Computer Sciences, U.B.C.
12:00	-	1:15	Lunch

SESSION FOUR - Friday P.M., Feb 22/85

Tour of MOE's Environmental Laboratory, 3650 Wesbrook Crescent, U.B.C. campus

Tour Chairman - Lawrence Lowe, Dept. of Soil Science, U.B.C.

Time

1:30 - 2:30 - tour of Environmental Laboratory. Transportation available from west side of MacMillan Bldg. at 1:15, or meet at Lab.

2:30 - 3:30 - tour of Environmental Laboratory. Transportation available from west side of MacMillan Bldg. at 2:15, or meet at Lab.

Tour participants are asked to segregate themselves into two groups, one for each tour.

APPENDIX 2

REGISTRANTS - 9th B. C. SOIL SCIENCE WORKSHOP

Mr. H. A. Luttmerding,
B. C. Ministry of Environment,
1873 Spall Road,
Kelowna, British Columbia.
V1Y 4R2

Mr. T. K. Ovanin,
Islands Trust,
Parliament Buildings,
Victoria, British Columbia.
V8W 3E1

Mr. B. E. Mauza,
B. C. Ministry of Agriculture & Food,
32916 Marshall Road,
Abbotsford, British Columbia.
V2S 1K2

Dr. J. D. Beaton,
Northwest Director,
Potash and Phosphate Institute,
P. O. Box 970,
Cochrane, Alberta.
TOL OWO

Mr. J. Fredericks,
403A, Gardiner Place,
Saskatoon, Saskatchewan.
S7N 2S9

Mr. A. Burdett,
B. C. Ministry of Agriculture & Food,
1873 Spall Road,
Kelowna, British Columbia.
V1Y 4R2

Dr. H. Schreier,
Dept. of Soil Science,
Univerisity of British Columbia,
2357 Main Mall,
Vancouver, British Columbia.
V6T 2A2

Mr. A. Goldin,
Dept. of Soil Science,
University of British Columbia,
2357 Main Mall,
Vancouver, British Columbia.
V6T 2A2

Mr. W. Carr,
Terrasol,
#506, 5932 Patterson Avenue,
Burnaby, British Columbia
V5H 4B4

Mr. R. Frank,
R.R. #4, Site 440, Box 5,
Courtenay, British Columbia
V9N 7J3

Ms. M. Vallance,
B. C. Ministry of Forests,
Research Laboratory,
4300 North Road,
Victoria, British Columbia.
V8Z 5J3

Dr. W. W. Bourgeois,
MacMillan-Bloedel Ltd.,
65 Front Street,
Nanaimo, British Columbia.
V9R 5H9

Ms. A. Gammell,
MacMillan-Bloedel Ltd.,
65 Front Street,
Nanaimo, British Columbia.
V9R 5H9

Ms. E. Zweck von Zweckenburg,
B.C. Agricultural Land Commission,
4940 Canada Way,
Burnaby, British Columbia.
V5G 4K6

Ms. A. Monetta
P. O. Box 834,
Aldergrove, British Columbia,
V0X 1A0

Dr. R. B. Smith,
Canadian Forestry Service,
506 W. Burnside Road,
Victoria, British Columbia.
V8Z 1M5

Dr. M. Sondheim,
B. C. Ministry of Environment,
553 Superior Street,
Victoria, British Columbia.
V8V 1X5

Mr. R. Colvey,
B. C. Ministry of Agriculture & Food,
1873 Spall Road,
Kelowna, British Columbia.
V1Y 4R2

Mr. D. Flegel,
B. C. Ministry of Agriculture & Food,
1873 Spall Road,
Kelowna, British Columbia.
V1Y 4R2

Ms. C. Reynolds,
B. C. Ministry of Agriculture & Food,
1873 Spall Road,
Kelowna, British Columbia.
V1Y 4R2

Ms. M. J. Douglas,
#203, 3670 West 5th Avenue,
Vancouver, British Columbia.
V6R 1S2

Mr. S. M. Smith,
#302, 2835 West 5th Avenue,
Vancouver, British Columbia.
V6K 1S6

Mr. A. G. Anderson,
B. C. Assessment Authority,
2023 Kendal Avenue,
Victoria, British Columbia.
V8P 1R7

Mr. R. H. Louie,
B. C. Ministry of Environment,
553 Superior Street,
Victoria, British Columbia.
V8V 1X5

Mr. R. Laird,
B. C. Ministry of Forests,
1434 Jefferson Avenue,
West Vancouver, British Columbia.
V7T 2B4

Mr. M. Nagy,
F.E.R.I.C.
#201, 2112 W. Broadway,
Vancouver, British Columbia.
V6K 2C8

Dr. M. Rowell,
Norwest Soil Research Inc.,
#203, 20771 Langley Bypass,
Langley, British Columbia.
V3A 5E8

Mr. N. Flore,
Western Co-op Fertilizer Ltd.,
147 Midcrest Crescent, S.E.,
Calgary, Alberta.
T2X 1B4

Mr. H. Quesnel,
B. C. Ministry of Agriculture & Food,
2127 Panaview Heights, R.R. #3,
Saanichton, British Columbia.
V0S 1M0

Ms. S. Burton,
3514 West 40th Avenue,
Vancouver, British Columbia.
V6N 3B8

Mr. W. Price,
Dept. of Soil Science,
University of British Columbia,
2357 Main Mall,
Vancouver, British Columbia.
V6T 2A2

Mr. R. Kowall,
B. C. Ministry of Environment
1873 Spall Road,
Kelowna, British Columbia.
V1Y 4R2

Mr. J. Senyk,
Canadian Forestry Service,
506 West Burnside Road,
Victoria, British Columbia.
V8Z 1M5

Mr. H. Chuah,
B.C. Ministry of Agriculture & Food,
1873 Spall Road,
Kelowna, British Columbia.
V1Y 4R2

Mr. S. Lindeburgh,
P.O. Box 4075,
Smithers, British Columbia.
V0J 2N0

Mr. J. Jungen,
B. C. Ministry of Environment,
1873 Spall Road,
Kelowna, British Columbia.
V1Y 4R2

Mr. A. B. Dawson,
B. C. Ministry of Agriculture & Food
1873 Spall Road,
Kelowna, British Columbia.
V1Y 4R2

Mr. D. Yole,
P.O. Box 3862,
Smithers, British Columbia.
V0J 2N0

Dr. J. C. Keng,
Agriculture Canada,
P.O. Box 1000,
Agassiz, British Columbia.
V0M 1A0

Mr. L. J. P. von Vliet,
Agriculture Canada,
6660 N. W. Marine Drive,
Vancouver, British Columbia.
V6T 1X2

Mr. G. G. Runka,
Land Sense Ltd.,
4695 Garden Grove Drive,
Burnaby, British Columbia.
V5G 3V2

Mr. E. Stathers,
Thorn EMI,
2138 West 13th Avenue,
Vancouver, British Columbia.
V6K 2S1

Mr. A. Inselberg,
4473 Canterbury Crescent,
North Vancouver, British Columbia.
V7R 3N8

Mr. W. Temple,
1060 East 50th Avenue,
Vancouver, British Columbia.
V5X 1B8

Mr. C. Sniady,
#204, 1176 West 11th Avenue,
Vancouver, British Columbia.
V6H 1K3

Mr. P. Christie,
B.C. Ministry of Agriculture & Food,
1873 Spall Road,
Kelowna, British Columbia.
V1Y 4R2

Mr. C. H. Brownlee,
B.C. Ministry of Agriculture & Food,
1873 Spall Road,
Kelowna, British Columbia.
V1Y 4R2

Mr. D. E. McLeod,
UBC Botancial Garden,
6501 N.W. Marine Drive,
Vancouver, British Columbia.
V6T 1W5

Mr. H. Hofmeyr,
B.C. Ministry of Agriculture & Food,
1873 Spall Road,
Kelowna, British Columbia.
V1Y 4R2

Mr. D. Sahlstrom,
Terrasol,
1637 Columbia Street,
North Vancouver, British Columbia.
V7S 1A5

Mr. A. Green,
Agriculture Canada,
6660 N.W. Marine Drive,
Vancouver, British Columbia.
V6T 1X2

Mr. G. Singleton,
B. C. Hydro and Power Authority,
555 W. Hastings Street,
Vancouver, British Columbia.
V6B 4T6

Mr. B. French,
RBF Land Resource Consultants Ltd.,
#104, 2333 Beach Drive,
Victoria, British Columbia.
V8R 6K2

Mr. A. Jakoy,
B. C. Institute of Technology,
3700 Willingdon Avenue,
Burnaby, British Columbia.
V5G 3H2

Ms. M. Christofferson,
Dept. of Soil Science,
University of British Columbia,
2357 Main Mall,
Vancouver, British Columbia.
V6T 2A2

Mr. A. Hennig,
Soil Management Services,
P.O. Box 455,
Beaverlodge, Alberta.
TOH OCO

Mr. T. Rollerson,
MacMillan-Bloedel Ltd.,
65 Front Street,
Nanaimo, British Columbia.
V9R 5H9

Dr. T. Ballard,
Dept. of Soil Science,
University of British Columbia,
Vancouver, British Columbia.
V6T 2A2

Ms. A. van Niekerk,
Pacific Forest Research Center,
506 West Burnside Road,
Victoria, British Columbia.
V8Z 1M5

Mr. D. Lousier,
B.C. Ministry of Forests,
1450 Government Street,
Victoria, British Columbia.
V8W 3E7

Mr. G. Still,
B.C. Ministry of Forests,
518 Lake Street,
Nelson, British Columbia.
V1L 4C6

Mr. W. Beese,
MacMillan-Bloedel Ltd.,
65 Front Street,
Nanaimo, British Columbia.
V9R 5H9

Dr. L. Lavkulich,
Dept. of Soil Science,
University of British Columbia,
2357 Main Mall,
Vancouver, British Columbia.
V6T 2A2

Dr. G. Kowalenko,
Agriculture Canada,
P.O. Box 1000,
Agassiz, British Columbia.
V0M 1A0

Ms. E. Dawson,
B. C. Ministry of Environment,
765 Broughton Street,
Victoria, British Columbia.
V8V 1X5

Mr. E. Kenk,
B. C. Ministry of Environment,
554 Superior Street,
Victoria, British Columbia.
V8V 1X5

Ms. S. E. A. Norman,
P. O. Box 408,
Lions Bay, British Columbia.
V0N 2E0

Ms. M. van Soest,
913 Thermal Drive,
Coquitlam, British Columbia.
V3J 6R4

Mr. R. Kline,
B.C. Ministry of Agriculture & Food,
Experimental Farm Site,
R.R. #8, RMD 7,
Prince George, British Columbia.
V2N 4M6

Ms. C. Hackinen,
4942 Fulwell Street,
Burnaby, British Columbia.
V5G 1P2

Ms. E. Kenney,
Agriculture Canada,
6660 N.W. Marine Drive,
Vancouver, British Columbia.
V6T 1X2

Mr. T. Guthrie,
Norwest Soil Laboratory,
14856 Bueva Vista Avenue,
White Rock, British Columbia.
V4B 1X4

Dr. M. Goldstein,
Soilcon Laboratories Ltd.,
805 W. 10th Avenue,
Vancouver, British Columbia.
V5Z 1L7

Dr. S. Chieng,
Dept. of Bio-Resource Engineering,
University of British Columbia,
2357 Main Mall,
Vancouver, British Columbia.
V6T 2A2

Mr. R. Bertrand,
Soils Branch,
B.C. Ministry of Agriculture & Food,
17720 - 57th Avenue,
Surrey, British Columbia.
V3S 4P9

Ms. R. Hardy,
3776 Yale Street,
Burnaby, British Columbia.
V5C 1P4

Mr. L. Lacelle,
B. C. Ministry of Environment,
1873 Spall Road,
Kelowna, British Columbia.
V1Y 4R2

Mr. C. Hilliard,
B.C. Ministry of Agriculture & Food,
1873 Spall Road,
Kelowna, British Columbia.
V1Y 4R2

Mr. D. Clarke,
2575 Grant Street,
Vancouver, British Columbia.
V5K 3G6

Dr. A. Bomke,
Dept. of Soil Science,
Univeristy of British Columbia.
2357 Main Mall,
Vancouver, British Columbia.
V6T 2A2

Mr. F. Nuszdorfer,
B. C. Ministry of Forests,
4595 Canada Way,
Burnaby, British Columbia.
V5G 4L9

Dr. L. Lowe,
Dept. of Soil Science,
University of British Columbia,
2357 Main Mall,
Vancouver, British Columbia.
V6T 2A2

Ms. C. Jones,
Reid Collins,
P. O. Box 430,
Aldergrove, British Columbia.
V0X 1A0

Dr. T. Lewis,
6149 Burns Street,
Burnaby, British Columbia.
V5H 1X3

Mr. R. H. Hitchman,
858 Baycrest Drive,
North Vancouver, British Columbia.
V7G 1N8

Dr. G. H. Neilson,
Agriculture Canada,
Research Station,
Summerland, British Columbia.
VOH 1ZO

Dr. D. S. Stevenson,
Agriculture Canada,
Research Station,
Summerland, British Columbia.
VOH 1ZO

Dr. D. Neilson,
Agriculture Canada,
Research Station,
Summerland, British Columbia.
VOH 1ZO

Dr. R. Hawes,
Norecol Environmental Consultants,
#100, 1281 West Georgia Street,
Vancouver, British Columbia.
V6E 3J3

Mr. R. Trowbridge,
B. C. Ministry of Forests,
Bag 5000,
Smithers, British Columbia.
VOJ 2NO

Mr. R. Emerson,
B. C. Ministry of Environment,
1873 Spall Road,
Kelowna, British Columbia.
V1Y 4R2

Mr. L. Husted,
CIP Forest Products,
8067 E. Saanich Road,
R. R. #1,
Saanichton, British Columbia.
VOS 1MO

Mr. M. Curran,
Dept. of Soil Science,
University of British Columbia.
2357 Main Mall,
Vancouver, British Columbia.
V6T 2A2

Ms. A. Eastham,
B. C. Ministry of Forests,
Research Laboratory,
4300 North Road,
Victoria, British Columbia.
VOR 2LO

Mr. D. Paton,
Chemex Laboratories,
2021 - 41 Avenue, N.E.,
Calgary, Alberta.
T2X 1E4

Mr. U. Wittneben,
B. C. Ministry of Environment,
1873 Spall Road,
Kelowna, British Columbia.
V1Y 4R2

Mr. J. A. Carson,
Alberta Agriculture,
Soil & Feed Testing Laboratory,
6909 - 116th Street,
Edmonton, Alberta.
T6H 4P2

Mr. J. Hall,
Agriculture Canada,
6660 N.W. Marine Drive,
Vancouver, British Columbia.
V6T 1X2

Mr. S. C. Chang,
6191 Winch Street,
Burnaby, British Columbia.
V5B 2L4

Mr. T. Nason,
10981 - 76 Avenue,
Edmonton, Alberta.
T5G 0J6

Dr. A. L. van Ryswyk,
Agriculture Canada,
3015 Ord Road,
Kamloops, British Columbia.
V2B 8A9

Mr. N. A. Gough,
B.C. Ministry of Agriculture & Food,
1873 Spall Road,
Kelowna, British Columbia.
V1Y 4R2

Ms. H. Williams,
#208, 1343 Harrison Street,
Victoria, British Columbia.
V8S 3R9

Ms. A. Macadam,
B. C. Ministry of Forests,
Bag 5000,
Smithers, British Columbia.
V0J 2N0

Mr. K. Broersma,
Agriculture Canada,
R. R. #8, RMD #6,
Prince George, British Columbia.
V2N 4M6

Mr. P. Epp,
B. C. Ministry of Environment,
1547 Skaha Lake Road,
Penticton, British Columbia.
V2A 7K2

Mr. W. Herman,
Pacific Soil Analysis Inc.,
1560 Rand Avenue,
Vancouver, British Columbia.
V6P 3G2

Mr. G. Garry,
D. H. Duncan & Co. Ltd.,
32864 - 12th Avenue,
Mission, British Columbia.
V2V 2M6

Ms. K. Falkiner,
Site 206, Unit 3,
P.O. Box 28, R.R. #2,
Campbell River, British Columbia.
V9W 5T7

Dr. K. Valentine,
Agriculture Canada,
6660 N.W. Marine Drive,
Vancouver, British Columbia.
V6T 1X2

Mr. T. Lord,
Agriculture Canada,
6660 N.W. Marine Drive,
Vancouver, British Columbia.
V6T 1X2

Dr. T. Baker,
B. C. Ministry of Forests,
1450 Government Street,
Victoria, British Columbia.
V8W 3E7

Ms. S. Ulansky,
Dept. of Soil Science,
University of British Columbia,
2357 Main Mall,
Vancouver, British Columbia.
V6T 2A2

Mr. G. Young,
R. R. #4, Deep Creek,
Kelowna, British Columbia.
V1Y 7R3

Dr. D. Moon,
Agriculture Canada,
6660 N.W. Marine Drive,
Vancouver, British Columbia.
V6T 1X2

Mr. P. A. Christie,
Talisman Land Resource Consultants,
300, 842 Thurlow Street,
Vancouver, British Columbia.
V5E 1W2

Mr. M. Peterson,
Dept. of Soil Science,
University of British Columbia,
2357 Main Mall,
Vancouver, British Columbia.
V6T 2A2

Mr. V. Korelus,
Pacific Forest Products Ltd.,
8067 East Saanich Road, R.R. #1,
Saanichton, British Columbia.
V0S 1M0

Dr. J. Wiens,
B. C. Ministry of Environment,
810 Blanchard Street,
Victoria, British Columbia.
V8V 1X5

Dr. W. van Lierop,
B.C. Ministry of Agriculture & Food,
1873 Spall Road,
Kelowna, British Columbia.
V1Y 4R2

Dr. C. A. Rowles,
1404, 4660 W. 10th Avenue,
Vancouver, British Columbia.
V6R 2J6

Mr. P. Synadinos,
Dept. of Soil Science,
Univeristy of British Columbia,
2357 Main Mall,
Vancouver, British Columbia.
V6T 2A2

Dr. M. W. Blades,
Department of Chemistry,
University of British Columbia,
Vancouver, British Columbia.
V6T 2A2

Dr. B. Woodham,
Dept. of Computer Sciences,
University of British Columbia,
Vancouver, British Columbia.
V6T 2A2

Dr. P. C. Pang,
Pacific Forest Research Center,
506 W. Burnside Road,
Victoria, British Columbia.
V8Z 1M5

Mr. J. Gadsby,
Gadsby Consultants Ltd.,
801, 1030 W. Georgia Street,
Vancouver, British Columbia.
V6E 2M9

Mr. D. Obratsky,
B.C. Ministry of Agriculture & Food,
1873 Spall Road,
Kelowna, British Columbia.
V1Y 4R2

Mr. D. J. Tomasiewicz,
Director,
Saskatchewan Soil Testing Lab.,
General Purpose Building,
University of Saskatchewan,
Saskatoon, Saskatchewan.
S7N 0W0